EVALUATION OF EMERGENCY-LOCATOR-TRANSMITTER PERFORMANCE IN REAL AND SIMULATED CRASH TESTS

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SUMMARY

Emergency-locator-transmitter (ELT) activation problems were investigated by testing a sampling of ELT units in actual airplane crashes and in a special test apparatus which simulated longitudinal crash pulses with superimposed local structural resonances. The objective of the study was to determine probable causes of excessive false alarms and nonactivations of ELT's during crash situations and to seek solutions to the current operational and technical problems. Experimental results from the study, which considered placement, mounting, and activation of ELT's under simulated crash impacts, and an evaluation of the sensitivity of ELT impact switches to orientation and to local structural vibrations are discussed.

INTRODUCTION

Most general-aviation airplanes have been required by law since the early 1970's (ref. 1) to carry emergency locator transmitters (ELT's). ELT units are self-contained, battery-powered, emergency-radio-transmitter beacons. Functionally, the ELT is triggered or activated by the deceleration imposed on the unit during a crash and are intended to aid Search and Rescue (SAR) in locating the crash site. From the outset, ELT's have suffered an excessive false-alarm rate as well as nonactivation problems during crashes. Initial efforts to overcome many of the technical and operational problems which occurred relative to the minimum performance standards of reference 2 were addressed in reference 3; however, the proposals were made without significant research to define the exact causes and to substantiate the proposed solutions to the problems. Consequently, many of the same problems still persist. For example, references 4 and 5 indicate from records examined that malfunctions of the deceleration sensitivity switch, corrosion problems, and human errors are still among the reported causes for unwanted ELT activations and that approximately 95 percent of all ELT alarms are nondistress situations. Thus, reliability and believability have severely limited the usefulness of these emergency devices.

Evaluation of the activation of ELT's in full-scale crash tests at Langley Research Center has been a part of the joint NASA/FAA Crash Dynamics Program which is aimed at developing technology for improved crash safety and occupant survivability in general-aviation aircraft (refs. 6 to 12). More recently, however, laboratory experiments on ELT sensor activation problems have been undertaken to support the work of Radio Technical Commission for Aeronautics

Special Committee 136. This committee was formed to assist the FAA and industry in seeking solutions to current ELT operational and technical problems. This paper presents the results of experiments on the activation of ELT's mounted in airplane structures and subjected to realistic crash impacts. The data are believed to be of general importance in understanding and dealing with the probable causes of the ELT false activations and providing solutions.

APPARATUS AND TEST PROCEDURE

Typical Emergency-Locator-Transmitter Units

Description of ELT units.- Figure 1 is a photograph of nine emergency locator transmitters (ELT's) typical of the units from various manufacturers. The units are among those used for evaluating the performance of sampling of in-service and off-the-shelf units under realistic crash impacts to determine the basic causes of ELT false activations and/or nonactivation.

The ELT is a relatively inexpensive, self-contained, battery-powered beacon designed to broadcast an emergency 121.5-MHz or 243.0-MHz radio signal automatically when triggered by the deceleration characteristic of an airplane crash. ELT's of primary concern in this study are of the "AF" or "AP" type. AF equipment is intended for permanent or fixed installation on the airframe; AP equipment may be attached or be portable. Typically, ELT's are less than 0.3048 m (1 ft) long and weigh only a few kilograms.

ELT mounts vary by type, airplane, and manufacturer's make and model as do the mounting locations in the airplanes. Locations can vary all the way from the cockpit area to the baggage compartment to the tail cone region. Typical mounts can vary from sturdy mounts, to mounts using velcro,[1] plastic ties, and mounts on non-airframe structure in the airplanes. This diversity in mounting techniques include improper and/or inadequate mounting of many ELT's and is likely to be one source of problems of nonfunctioning and/or false activations of some units. Installation was not variable for the study of this report, however, since each ELT was attached to the tail cone structure using state-of-the-art techniques. Figure 2 shows a typical mounting assembly used during the tests.

ELT impact sensor specifications.- The units are triggered by an impact sensor which is an acceleration-sensitive switch (a primary component of ELT's) activated by a force along one or more axes. Present specifications for automatic activation of ELT's are: for decelerations equal to or greater than $5.0g \pm {}^{2.0}_{0.0}g$ ($1g = 9.80$ m/sec^2 (32 ft/sec^2)) and durations equal to or greater than $11 \pm {}^{5.0}_{0.0}$ msec, the unit must activate; for decelerations and times below these, the ELT must not activate. (See ref. 2.) These specifications apply primarily to crash decelerations parallel to or coincident with the longitudina

[1]Trade name of Velcro Corporation.

axis of the aircraft. More recently a recommendation (ref. 3) to change a criterion for activation has received some consideration. The new proposal is: for decelerations equal to or greater than 2.0g ± 0.3g and a velocity change (ΔV) greater than or equal to 1.067 ± 0.152 m/sec (3.5 ± 0.5 ft/sec), the sensor must activate the ELT; under all other conditions, the sensor must not activate. If the switches do not operate within the specified crash parameters, the unit may be susceptible to unwarranted activation or nonactivation under situations that should or should not activate them. Of the ELT's tested, three different switch types were represented: a cantilever beam (wire) with tip mass; a ball and magnet; and a rolomite[2] switch. Details of the switches are discussed in subsequent sections.

Crash Environment Determination

The initial step in the program for evaluating the performance of ELT's during crash situations was to record the longitudinal decelerations on FM tape during the various NASA full-scale crash tests of references 6 to 12. These data were analyzed (1) to determine the type of crash environment one might expect the ELT's to be subjected to during crash situations (for example, the primary loads and any secondary inputs) and (2) to help establish the crash pulse needed for simulation in a laboratory apparatus to permit repetitive, quick-turn-around tests on ELT's.

Crash pulses.- Typical measured longitudinal decelerations are presented in figure 3 for crashes of three different airplanes on concrete and dirt surfaces. The data are from accelerometers located on relatively rigid structure in the cabin area of the airplanes. These data show the nature of an actual environment the ELT can be subjected to in a crash situation. Figure 3(a) is for the crash test onto concrete. The top trace is the measured data with substantial high-frequency structural vibrations superimposed on the much lower frequency crash pulse. The bottom trace is smoothed data which show the underlying low-frequency, triangular-shaped crash pulse. The smoothing was accomplished using a least-squares fit reduction technique discussed in reference 7.

Two crash test decelerations for impacts on dirt are shown in figure 3(b). Basically no difference is noted between the crash pulses on dirt and on a concrete surface. (Compare fig. 3(a) and fig. 3(b).) The data of figure 3(b) also show the same high-frequency, local structural vibrations of the airplane overlayed on the low-frequency pulse evident in the smoothed data.

Structural resonances.- Since the basic crash pulses almost always have structural resonances superimposed on them, limited vibration data were obtained on several different types of general-aviation airplanes to determine the typical frequency range for airplane structural resonance.

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[2]Invention of Sandia Laboratories.

Accelerometers with conditioning equipment and an oscillograph recorder were used for determining the characteristic airplane resonances. The accelerometer was mounted to bulkheads, ELT mounts or beams in the cabin, and/or tail cone region of seven different airplanes. A large rubber mallet was used to rap some hard point of the airplane to excite the structure in the longitudinal direction. Oscillograph traces of the vibrations were used to determine the predominant frequency. Characteristic resonances in the seven airplanes range from approximately 35 to 200 Hz.

The data for figure 3 indicate that the longitudinal deceleration pulse measured in actual crash tests at the Langley Research Center (LaRC) is basically a low-frequency, triangular-shaped pulse well below 10 Hz with superimposed structural vibrations also evident in the range of 35 to 200 Hz depending upon the mounting location and type of light airplane. Although the airplane crash test parameters associated with these data cannot be considered comprehensive for all crash situations encountered by light airplanes, they are believed to be typical of a majority of crashes, especially those where some structural crushing occurs.

ELT Impact Test Apparatus

Based upon observations made of the nature of basic crash deceleration pulses from actual experimental LaRC crash tests and the structural resonances from seven general-aviation airplanes, a test apparatus capable of being repetitively used was fabricated for testing various ELT units in a realistic simulated crash environment. (See fig. 4.) The apparatus provides a convenient, realistic, and economical laboratory method of extending the test data on ELT's acquired during crash tests of full-sized airplanes at the Langley Impact Dynamics Research Facility. For example, figure 5 is a comparison of the longitudinal deceleration on an ELT in a crash test with a simulated crash pulse in the impact test apparatus. As indicated in the figure, both the characteristic shape of the crash pulse and structural resonances are reproduced by the test apparatus. It should be noted that the test apparatus was designed to give the same basic deceleration pulse with superimposed structural resonances but with lower maximum deceleration values than actual crash tests. The function of the apparatus was to test ELT's which are supposed to activate in the 5g to 7g rang of impact decelerations.

Description of impact apparatus.- The laboratory apparatus for testing ELT's to evaluate their performance is shown in figure 4. The test setup (an adaptation of the concept in ref. 13) consists of a 1.83 m (6 ft) diameter by 1.23 m (4 ft) long steel cylindrical section with a 1.23 m (4 ft) length of an actual airplane tail cone section mounted on a platform inside the cylindrical section. A number of attachments between a ring frame at the base of the tail section and the platform permitted tuning of the basic tail cone natural frequency. The oscillations noted on the deceleration traces with the test apparatus were the vibrations of the tail cone at its natural frequency on the platform. The sudden release of the apparatus excites this vibration during free fall and the impact excites the much higher amplitude vibration superimposed on the basic deceleration pulse. (See fig. 5.) Two 1.22 m (4 ft) long by 0.46 m (1.5 ft) deep, 60° wooden wedges attached to the test apparatus shape

the crash pulse upon impact into a 0.609-m (2-ft) depth of glass beads. The glass beads ranging in size from 420 to 595 μm (0.0165 to 0.0234 in.) were used as the impact medium because of their uniformity and reduced susceptibility to moisture and for repeatability. The steel cylinder can be rotated relative to the wedges to vary the vector input for off-axis studies.

Instrumentation.- The ELT impact test apparatus was instrumented with strain-gauge-type accelerometers having flat frequency response from dc to 2000 Hz. The accelerometer signals were routed through a calibration unit and a galvanometer driver to oscillograph recorders with galvanometers (fig. 4) which had flat frequency responses from dc to 2500 Hz. Decelerations at the base of the tail cone, on bulkheads, on webs, at the ELT brackets, and on the ELT units were recorded along with ELT activation/no activation signals whenever possible. A radio receiver tuned to 121.5 MHz was also used to monitor all the ELT activations.

Test procedure.- Once accelerometers (oriented perpendicular and parallel to the ELT sensitivity axis) were attached to the ELT, the unit was installed in the tail cone and the ELT was armed to ready the unit. The entire apparatus was then raised to a given drop height above the impact surface by an overhead hoist using a cargo hook for quick release. A push-button switch activated the oscillograph recorders. A second switch was then used to electrically release the cargo hook to drop the apparatus. Penetration of the wedges into the bed of glass beads decelerated the system; thus, loads were imposed on the test apparatus and ELT. If the deceleration from a drop was too low to activate the ELT, the drop height was increased, the glass beads releveled, and the test repeated until the impact loads were sufficient to activate the ELT unit. Tests were repeated at drop heights just above and below the activation threshold to bracket the deceleration level for activation. The drop height ranged between 0 and 1.07 m (0 and 3.5 ft). Except for the orientation angle of the tail cone relative to the wedges, the off-axis studies were carried out with the same procedure.

ELT Switch Vibration Test Apparatus

Because of the possible sensitivity of the ELT impact sensors or switches to high-frequency vibrations, additional impact tests and sinusoidal vibration tests were conducted to evaluate the sensitivity of the impact sensors to vibratory inputs.

Description of ELT inertia switches.- As noted previously, three different switch types were used in the ELT's examined in the study: (1) a cantilever beam (wire) with tip mass and silicone oil medium (fig. 6(a)), (2) a ball and magnet with a calibrated field intensity (fig. 6(b)), and (3) a rolomite switch (fig. 6(c)). The first two switch types work in conjunction with a holding transistor (SCR) which electronically latches the transmitter in the ON position after a chosen time delay or contact level.

The principle of operation of the cantilever beam switch is that when a force deflects the tip mass against the metal ring of the switch case for sufficient time, the ELT electronics are activated. For the ball and magnet when the force due to an acceleration exceeds the holding force of the magnet, the

ball moves away from the magnet and closes the ELT electronics circuit. The rolomite switch does not necessarily require a holding circuit. In this switch, an inertial mass (hollow brass cylinder) is held by a blade spring wrapped around it. A second buckled blade spring is held close to two contacts. Under sufficient impact, the inertial mass strikes the blade spring causing it to snap through in the opposite direction to close the contacts and remain (theoretically) in this position until manually reset.

To aid the study and understanding of switch behavior, an experimental, low-frequency switch of the cantilever beam type was built for testing. A photograph of the assembled and disassembled switch is shown in figure 7. The switch had a thin brass cylindrical case with a metal cap on one end and a threaded insert for holding the cantilever beam on the other. The cantilever beam with tip mass was tuned to have a resonance of 14 Hz; the activation level was set for 5g to 7g; silicone oil provided the desired damping. A frequency of 14 Hz for the switch was chosen since it was between the 4 to 6 Hz basic force pulses and the local structural resonances of 30 to 200 Hz.

Description of switch vibration apparatus.- In addition to the instrumentation used with the impact apparatus, figure 8 shows the additional apparatus used for conducting the ELT switch vibration study. A permanent magnet shaker with required electronics was used for vibrating the base of a beam clamped in a vise. The inertia switches were mounted to the tip of the beam. The cantilever beam approach permitted the necessary displacements at the low-frequency vibrations with the limited ±0.635-cm (±0.25-in.) displacement capability of the shaker.

Instrumentation.- The same accelerometers and conditioning and recording equipment used for the impact tests were also used during the switch studies. Along with a test switch, an accelerometer for measuring the acceleration on the switch was attached to the tip of the cantilever beam. An oscillator signal routed through a power amplifier was used to drive the permanent magnet shaker. A 9-V dc battery wired across the switch provided a means of detecting switch closure. An oscillograph recorder was used to record the vibratory accelerations and the switch closure signals.

Test procedure.- With the ELT switch and accelerometer mounted to the tip of the cantilever beam, the length of the beam was adjusted in the vise clamp to give frequencies between approximately 5 and 100 Hz. The calibration unit was used to calibrate the accelerometer output on the oscillograph recorder to a desired range. The oscillator frequency was tuned to the beam resonance and the amplitude slowly increased until switch closure was noted. An oscillograph record was then made of the acceleration and switch closure signals for determining the activation level of the switch. The length of the beam was again adjusted for a different resonant frequency and the process repeated to obtain switch activation acceleration levels versus excitation frequency.

RESULTS AND DISCUSSION

Field Crash Tests of ELT's

Test data on ELT's have been acquired during crash tests of full-size aircraft at the Langley Impact Dynamics Research Facility. For example, figure 9 shows the different ELT's mounted in the cabin and tail cone area of a test airplane. Tests were conducted on the ELT's in two separate crash tests. The impact parameters were 27 m/sec (60 mph) for the two tests onto a concrete surface at (a) -30° flight path, -30° pitch and (b) -15° flight path, -15° pitch. Figure 10 presents the longitudinal decelerations on the airplane structure and the ELT units for the tests.

-30° flight path.- Decelerations at the -30° flight path are presented in figure 10(a). The top of figure 10(a) shows the recorded and filtered (20-Hz low pass filter) decelerations in the cabin area. The two histories at the top are on the cabin structure whereas the next two are on the ELT unit. The bottom of figure 10(a) presents similar data for the tail area. The data indicate the presence of similar high-frequency local vibrations prevalent in the crash tests discussed in the section "Crash Environment Determinations." The filtered data show that the low-frequency underlying crash pulse was approximately 15g which is well above the 5g to 7g threshold for ELT activation. A comparison of the ELT data in the tail cone area with those in the cabin indicates that the superimposed high-frequency vibrations were of somewhat lower magnitude in the tail than in the cabin, however; the basic crash pulse loading in this region of the airplane was also approximately 15g. The ELT in the cabin activated during the crash. In the tail, one of the two ELT's failed to activate; yet when the ELT was removed from the airplane immediately after the crash test and swung by hand, it did activate.

-15° flight path.- Figure 10(b) presents decelerations for the identical locations and the identical ELT units for the -15° flight-path crash test. A comparison of figure 10(b) with figure 10(a) indicates that both the superimposed local structural vibrations and the underlying crash pulse were lower for the -15° flight-path crash test. Likewise a comparison of the decelerations in the tail with decelerations in the cabin area (at the -15° flight path) indicate the attenuation of the magnitude of the local vibrations in the tail. The lower deceleration in the tail is reasonable since the area is further behind the initial contact region than the cabin. Furthermore the low-frequency crash pulse, between 5g and 10g (also above the 5g to 7g ELT activation threshold), is lower in magnitude and longer in duration than the -30° crash because at the lower angle there is less energy taken out in the initial impact and the airplane slides forward at a higher speed. ELT activations and nonactivations were identical to the previous -30° flight-path crash test. Once again when the ELT which failed to activate during the crash was removed and swung by hand, it activated. These types of behavior are typical of what has occurred in many cases and is one reason for exploring the vibration sensitivity of ELT inertia switches.

Impact Tests of ELT's

Figure 11 presents experimental results from the laboratory impact tests of 11 ELT units representing 7 different manufacturers. The ELT's represent both in-service and off-the-shelf units. Decelerations on the ELT units are presente as a function of time in milliseconds and activation status is noted.

Out of specifications - below threshold.- Typical longitudinal decelerations on three of five ELT units that activated during the impact study well below the proper specified threshold activation level of 5g are shown in figure 11(a). The structural resonance of the airplane tail cone may be noted on all the deceleration traces. Typically for these ELT units, the impact apparatus had to be lowered until the impact wedges (fig. 4) were just touching or actually penetrating the glass beads before activation of the units would not occur upon impact of the test apparatus.

Out of specification - above threshold.- Figure 11(b) presents longitudinal decelerations on two of three ELT units that did not operate at the proper specified deceleration level although, as noted in the figure, the ELT units experienced sufficient deceleration magnitude and time (T) durations to have activated even at the upper allowed 7g level. These particular ELT units also failed to properly activate even from the upper limit of impact velocity of the apparatus of approximately 4.57 m/sec (15 ft/sec).

Within specifications.- Decelerations for two of three units that activate within the ELT activation specification levels are shown in figure 11(c). The top traces are for one unit; the two bottom traces are for a second ELT. The upper traces for each ELT (labeled "ELT ON") show that when the ELT's experienced a deceleration pulse greater than 5g for at least 12.5 msec, activation of the unit occurred (activation verified by radio receiver). Similarly, the deceleration on the same unit at a slightly lower impact velocity shows that the magnitude of the deceleration was not above 5g for sufficient time and the ELT properly did not activate (traces labeled "ELT OFF"). A comparison of the measured time to reception of signal from ELT's indicates a wide spread in delay time for transmission to occur. Whether some part of the delay was a result of some of the units being out of specifications could not be assessed from these tests.

Off-Axis Impacts

The previous data are for impacts along the longitudinal axis of the tail cone in the ELT impact test apparatus. Tests were also conducted to evaluate off-axis impacts on the activation of ELT's. The cylindrical section with the airplane tail cone mounted on the platform (fig. 4) can be rotated relative to the impact wedges of the ELT impact test apparatus. Any angle between 0° and 90° can be obtained in this fashion so that the impact wedges can be set at any desired angle to the sensitivity axis of the ELT mounted in the tail cone. Figure 12 illustrates typical results of the off-axis deceleration input study. Angles, α, of 0°, 15°, 30°, 45°, and 90° were used in the investigation. An ELT which was within the activation specification levels was used in the tests. The data illustrated in figure 12 are for an angle

of 30°. In the top part of the figure, the component of the impact deceleration acting along the longitudinal sensitivity axis of the ELT was of sufficient magnitude to exceed the activation threshold and the ELT activated. On the other hand, the bottom figure shows that at a slightly lower deceleration level, the magnitude of the component along the sensitivity axis of the ELT was not sufficient to activate the ELT. Analysis of all the off-axis data indicated that, as expected, if the component of deceleration along the ELT sensitivity axis is greater than the 5g threshold, the ELT activates and forces perpendicular to the sensitive axis of the ELT did not cause activation problems.

Anomalous Activations

Figure 13 illustrates anomalous behavior exhibited by an ELT unit used in the impact tests. The deceleration trace at the top of the figure is for an impact with the ELT mounted in the tail cone of the ELT impact test apparatus. As may be noted in the first two traces in the figure, the ELT experienced deceleration magnitude and duration well exceeding the 5g and 7g threshold levels but the ELT did not properly activate. However, when the ELT was removed from the tail cone and whirled by hand to produce the deceleration (bottom trace) that just exceeded the 5g threshold, the ELT activated. Based upon these results, it was concluded that the cantilever beam inertia switch was being affected by the higher frequency vibrations. Additional results on the evaluation of the sensitivity of the impact sensors to local vibrations are discussed in subsequent sections.

ELT Switch Vibrations and Analysis

Several of the ELT impact switches were mounted in the ELT impact test apparatus (fig. 4) for evaluation, and sinusoidal vibration tests with the apparatus shown in figure 8 were also conducted to evaluate the sensitivity of impact sensors. Results of these tests are shown in figures 14 to 16.

Inertia switch chatter.- Figures 14(a) and 14(b) indicate that ELT sensors respond to the structural vibrations superimposed on the lower frequency input deceleration pulse obtained with the impact test apparatus. Figure 14(a) shows results for two cantilever beam switches. The top trace in the figure is the impact deceleration, whereas the lower two traces are switch contacts for both a 5g and a 7g threshold switch. The contact of the switches is being affected by the higher frequency vibrations on the input deceleration pulse. Responses of a ball and magnet and a rolomite switch to pulse inputs with higher frequency vibrations are shown in figure 14(b). The top traces are the input to the ball and magnet switch and the switch contact behavior. The two bottom traces are for the rolomite switch. Both sensors show chatter from the superimposed higher frequency structural vibrations.

The impact behavior of the experimental low-frequency switch is shown in figure 14(c). The top trace in the figure shows the deceleration pulse with the higher frequency vibrations, which was imposed on the experimental switch. Neither the underlying deceleration pulse nor the vibrations caused the switch to make contact in this case. In the bottom trace, a deceleration pulse

exceeded the activation threshold of the low-frequency switch, and switch contact occurred. Data for these tests indicate that the switch made contact as it should have but was not affected by or was sensing the higher frequency structural vibrations present on the basic input pulse. This behavior is highly desirable to minimize possible false activations from structural vibrations during noncrash situations or nonactivations during crashes because of the vibration-induced on-off—on-off contact of the switch which may prevent ELT electronic latching times from being achieved.

Switch vibration sensitivity.- In figure 15, a classical plot used to describe the behavior of a simple oscillator is presented to allow a comparison between the response of the experimental low-frequency switch (14-Hz cantilever) and a commercial switch (44-Hz cantilever). In nondimensional terms, the ratio of the switch gap displacement Δ (for switch contact to occur) to the switch base acceleration $\ddot{U}$ at contact is given as a function of the ratio of sinusoidal forcing frequency ω to the undamped switch natural frequency ω_n. Three curves for damping ratios C/C_c of 0.0, 0.7, and 2 are presented out of the family of curves possible depending on the damping values (C is actual damping and C_c is critical damping). As indicated in the figure, the experimental 14-Hz switch had a damping ratio of 0.7. The switch will respond identically to the amplitude of input frequencies up to essentially its undamped frequency of 14 Hz ($\omega/\omega_n = 1$) but becomes less responsive to those frequencies above 14 Hz. For example, at approximately 42 Hz, 3 times the natural frequency ($\omega/\omega_n = 3$), the response ratio is only 0.1. On the other hand with its higher natural frequency, the commercial 44-Hz switch (with $C/C_c = 2$) still has a ratio of 1/10 at approximately 88 Hz ($\omega/\omega_n = 2$). The important point to note is that, even being more highly damped, the commercial switch is too sensitive to the frequencies in the range of 30 Hz and above which places it too much into the purely local structural vibration regime of airplanes. Data on switches presented in the form of this figure also allow one to readily determine the damping ratio in the sensor during experimentation with a switch design of a known undamped natural frequency. By testing the switch at $\omega/\omega_n = 1$, the switch damping can be found from a nondimensional plot such as shown here.

In figure 16, additional results from the switch sensitivity tests are presented for both the experimental 14-Hz cantilever switch and the 44-Hz commercial cantilever switch of the previous figure along with ball and magnet switches, one a unidirectional and one with a radial sensitivity. Switch base displacement for switch contact to occur is plotted as a function of the excitation frequency. Lines of constant g units are also shown in the figure for reference. The data indicate that below approximately 20 Hz the experimental cantilever switch, the commercial switch, and the two ball and magnet switches respond essentially the same. The only difference between the 44-Hz commercial cantilever and the other switches is that it is a 7g threshold switch instead of a 5g switch. Note, however, that, above approximately 20 Hz, the displacement of the switch base for switch contact to occur approaches the switch gap of 6.35 mm (0.25 in.) in the 14-Hz experimental switch whereas the 44-Hz switch displacement continues to decrease and approaches its switch gap of 0.635 mm (0.025 in.) at much higher frequencies. At the higher frequencies, the accelerations of the low-frequency 14-Hz switch must be very large before switch contact can occur. On the other hand, the 44-Hz commercial switch

makes contact at substantially lower displacements; for example, at 44 Hz the commercial switch will make contact at 24g, whereas 50g is required for the 14-Hz switch. Similarly, at 100 Hz, the commercial switch will contact at 54g, but the low-frequency switch requires 260g for contact to occur.

Data for the two different ball and magnet switches are quite revealing. At the low end below 20 Hz, the response is essentially the same as the other type of switches. However, with increasing frequency the g level for contact of the switch continues to be essentially 5g to 6g. At approximately 90 Hz, the level increased to only 9g. It is interesting to note that in reference 5, an ELT brand which had one of the worst false activation records was one that uses the ball and magnet switch. Based upon the data in this figure, that record can be better understood.

Thus from the switch sensitivity study, it can be seen that, by the design of the switch resonance, the sensor can be made less sensitive to higher frequency structural responses but at the same time still be sensitive to the low-frequency crash-type pulses of actual interest. The less sensitivity to the higher frequencies is beneficial both during normal operations and during crash situations. During normal operations the g units would have to be extremely high (very unlikely) before switch contact could occur. During crash situations, although present on the crash pulse, the sensor would be less likely to be confused by the responses if they were large enough in magnitude to cause switch contact. Furthermore, it is not difficult to see local resonances with periods both below and above ELT electronic latching times. This could lead to activation problems as well as false activations from vibratory input.

SUMMARY OF RESULTS

This paper has presented the results of full-scale crash tests and laboratory impact tests and vibration studies on emergency-locator-transmitter (ELT) activation problems. The results from these studies are summarized as follows:

(1) Data from crash tests at the Langley Research Center indicate that the longitudinal crash environment imposed on ELT's in crash situations is basically a low-frequency loading pulse well below 10 Hz; however, high amplitude, local structural resonances which may be between 30 to 200 Hz, are superimposed on the crash pulse.

(2) With regard to frequency of structural vibrations and basic shape of deceleration pulse, good correlation was obtained between simulated crash pulses with superimposed structural vibrations in a special ELT impact test apparatus and actual crash test results.

(3) Crash tests and laboratory impact tests indicated similar erratic activation behavior of ELT units.

(4) Many ELT units did not operate within the specified activation threshold.

(5) Impact sensors typical of those used in ELT's were found to be too sensitive to structural vibrations.

(6) The vibration sensitivity of the impact sensors is undesirable since local structrual vibrations of the airplane could cause unwarranted activations during normal airplane operations or prevent the sensors from properly activating the ELT in a crash situation (depending on the frequency of the vibrations).

(7) A low-frequency switch design was found to possess desirable response characteristics in that it is sensitive to low-frequency crash pulses and the inherent nature of the design is less sensitive to higher frequencies in the range of local structural vibrations.

(8) Research results from this study and others will form the basis of recommendations to FAA and Industry on ELT's through a Radio Technical Commission for Aeronautics (RTCA) report.

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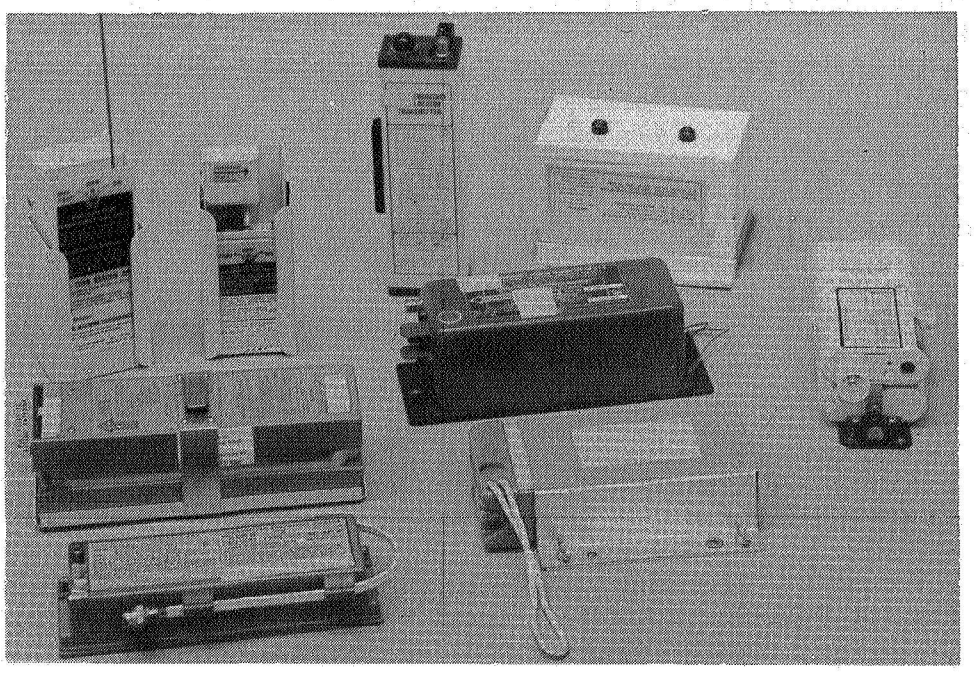


Figure 1.- Typical ELT's.

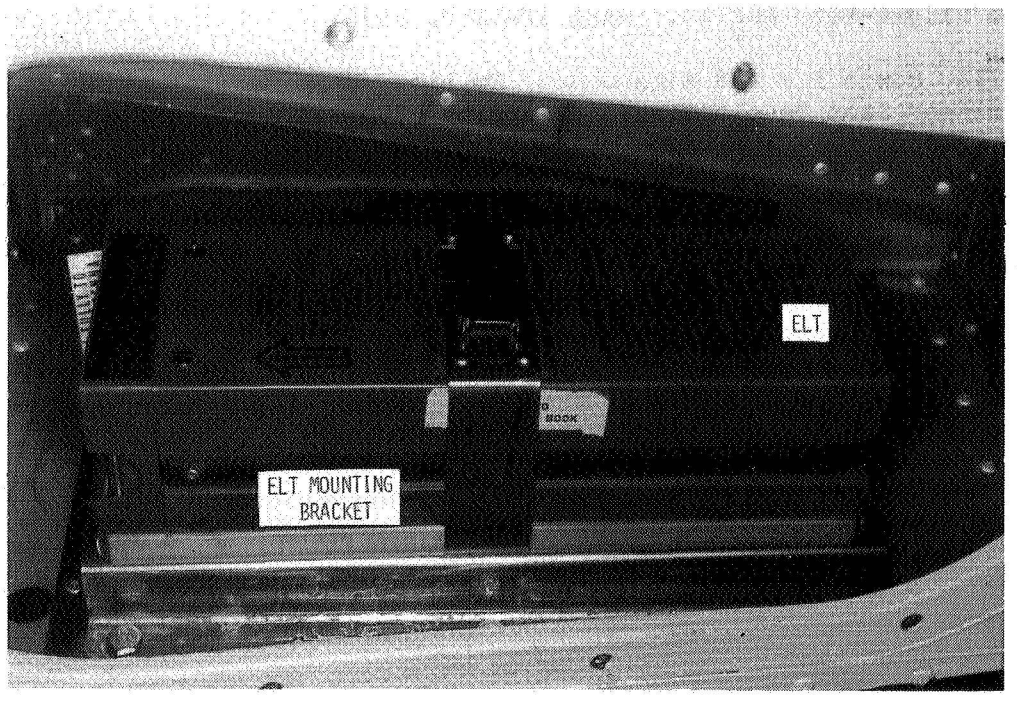
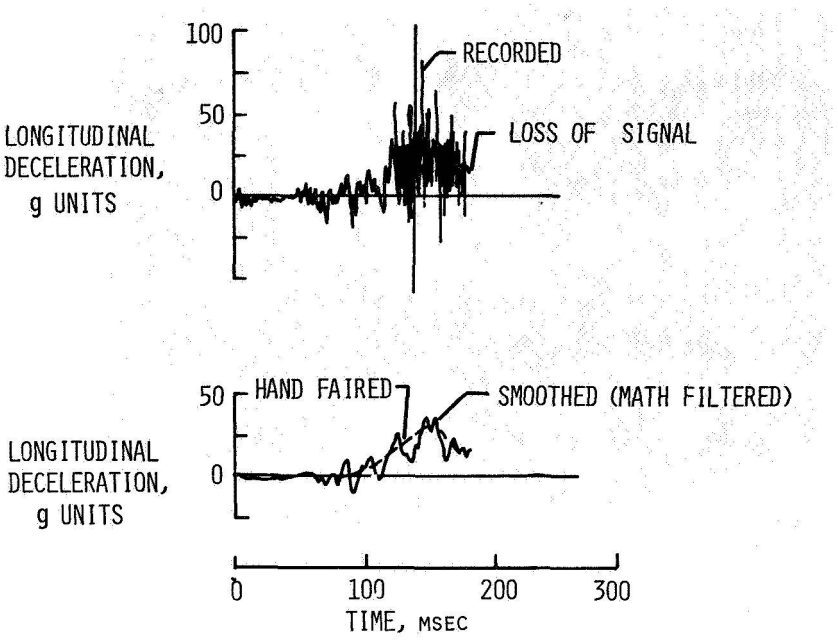
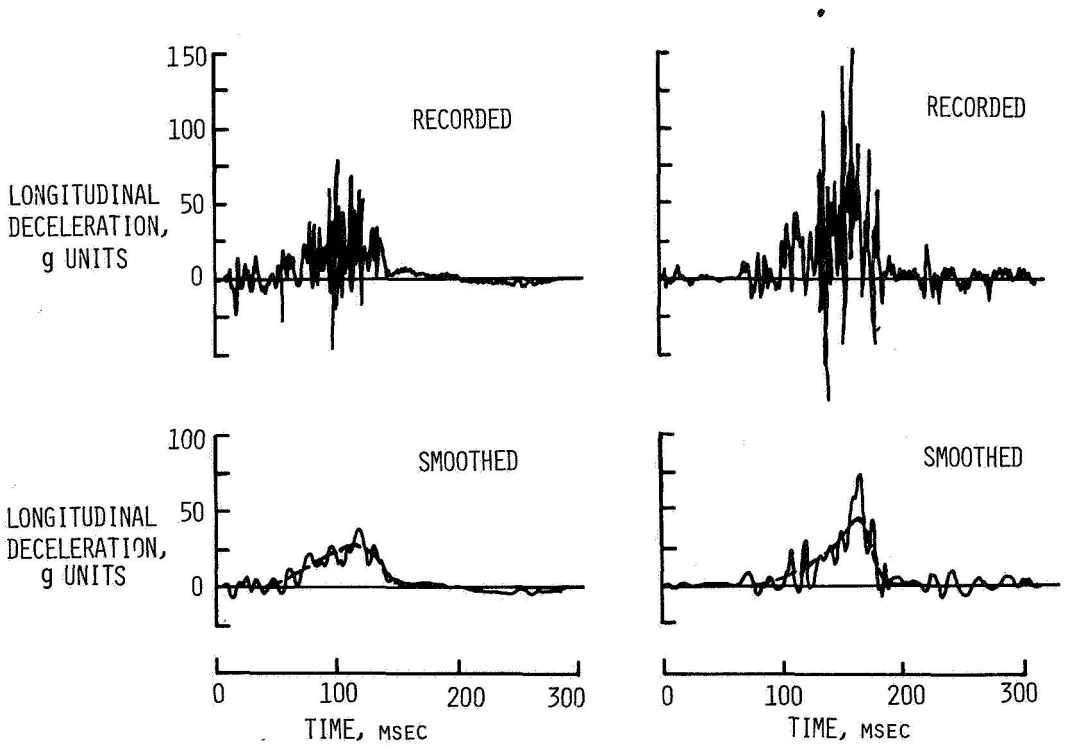


Figure 2.- Typical mounting assembly used in tests.



(a) Concrete surface.



(b) Dirt surfaces.

Figure 3.- Typical measured longitudinal deceleration pulses for three different airplanes.

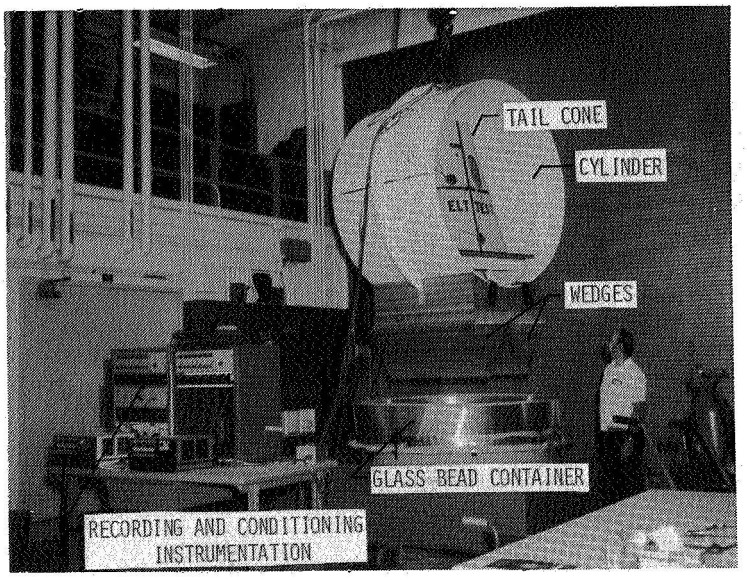


Figure 4.- Laboratory ELT impact test apparatus.

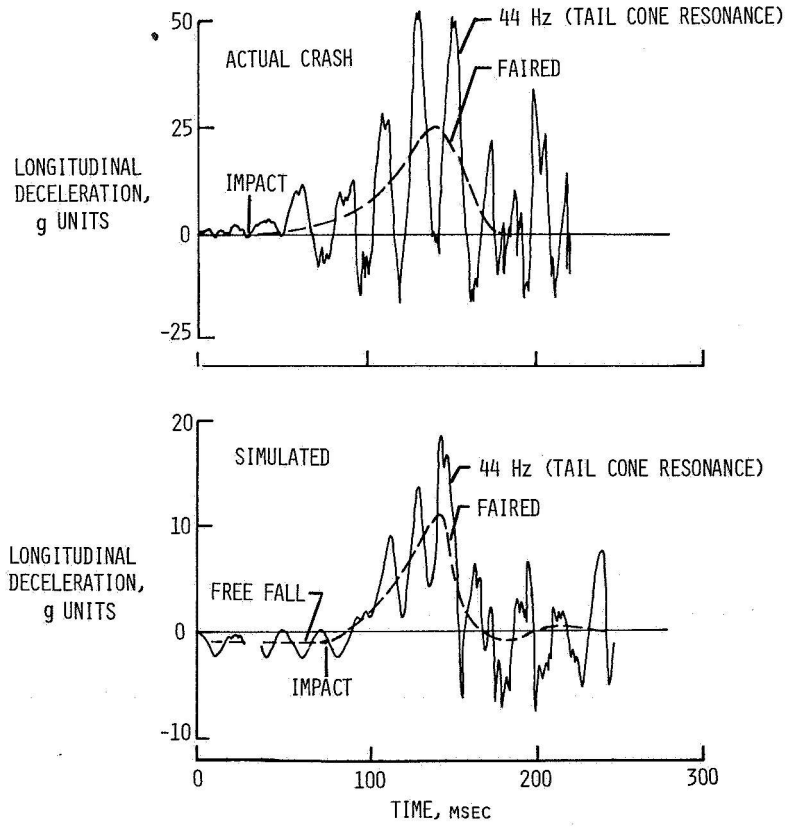
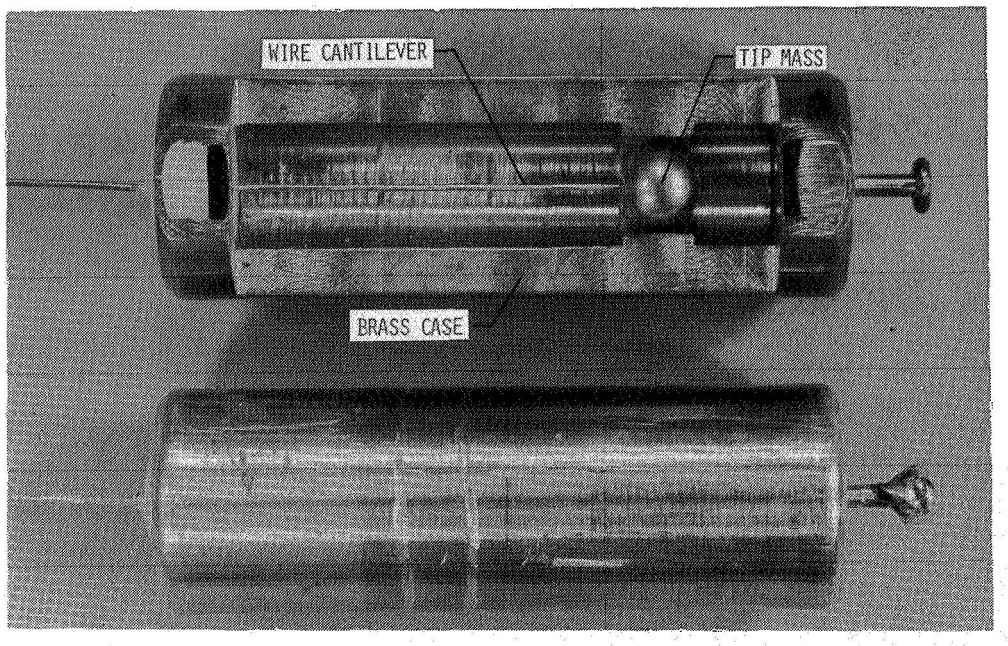
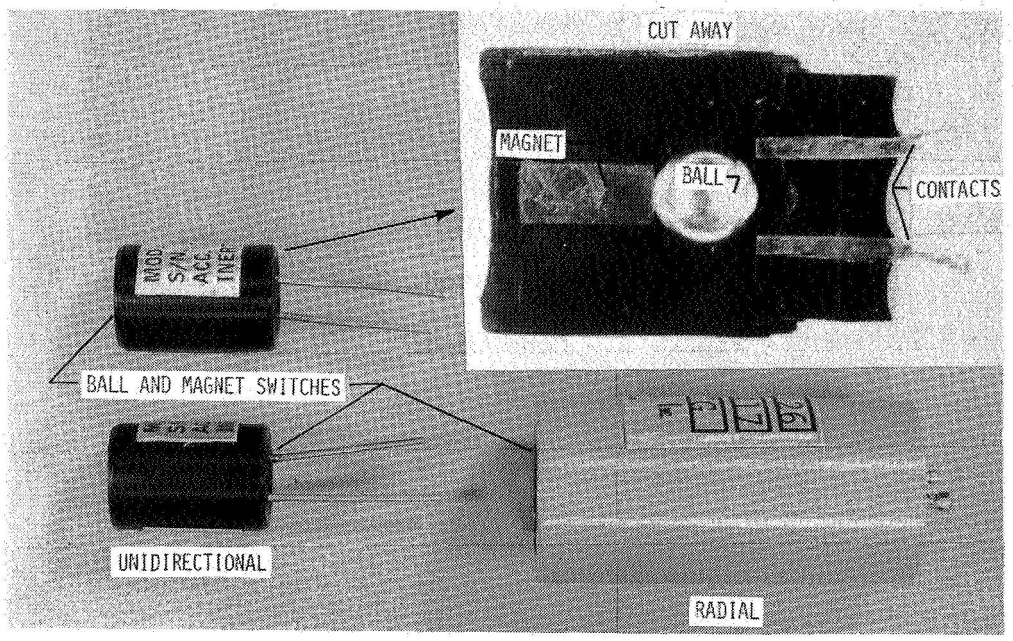


Figure 5.- Comparison of actual and simulated longitudinal deceleration crash pulse on ELT.

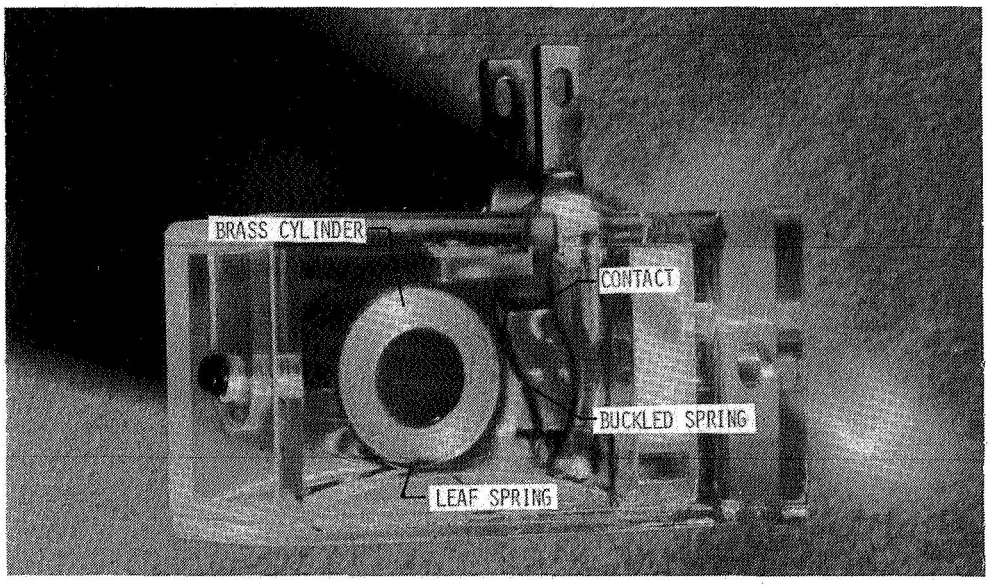


(a) Cantilever beam switch.



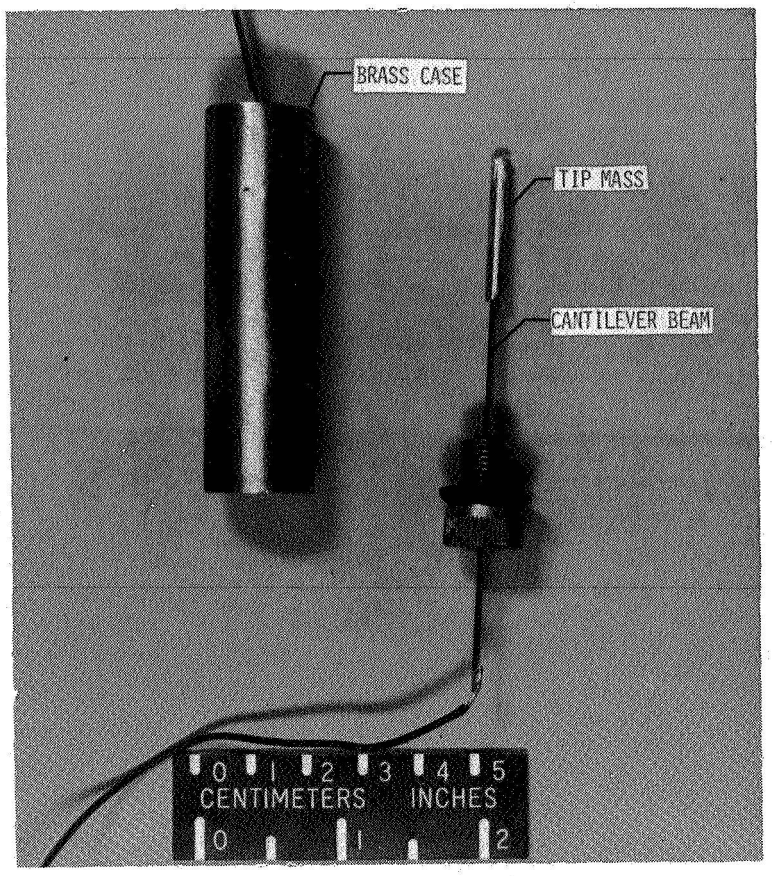
(b) Ball and magnet switches.

Figure 6.- Typical ELT inertia switches.

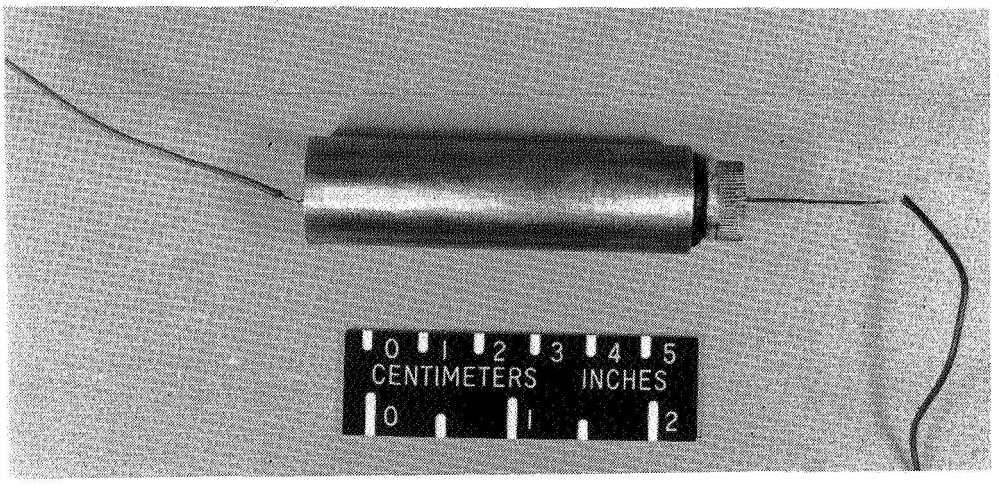


(c) Rolomite switch.

Figure 6.- Concluded.



(a) Disassembled.



(b) Assembled.

Figure 7.- Experimental low-frequency switch.

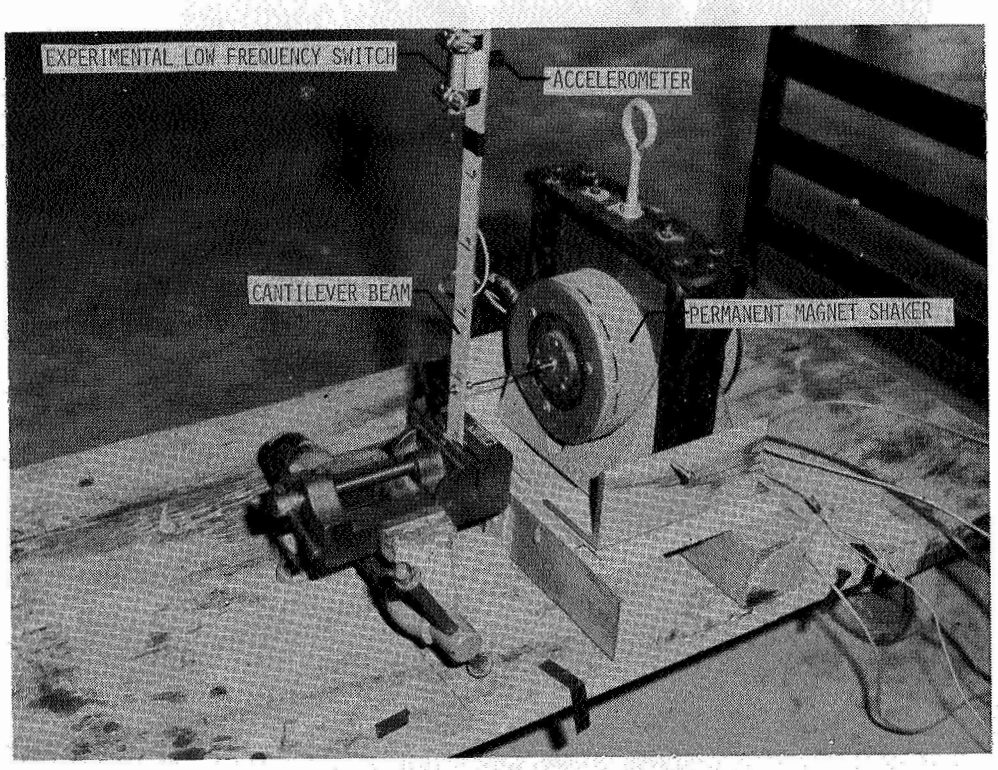
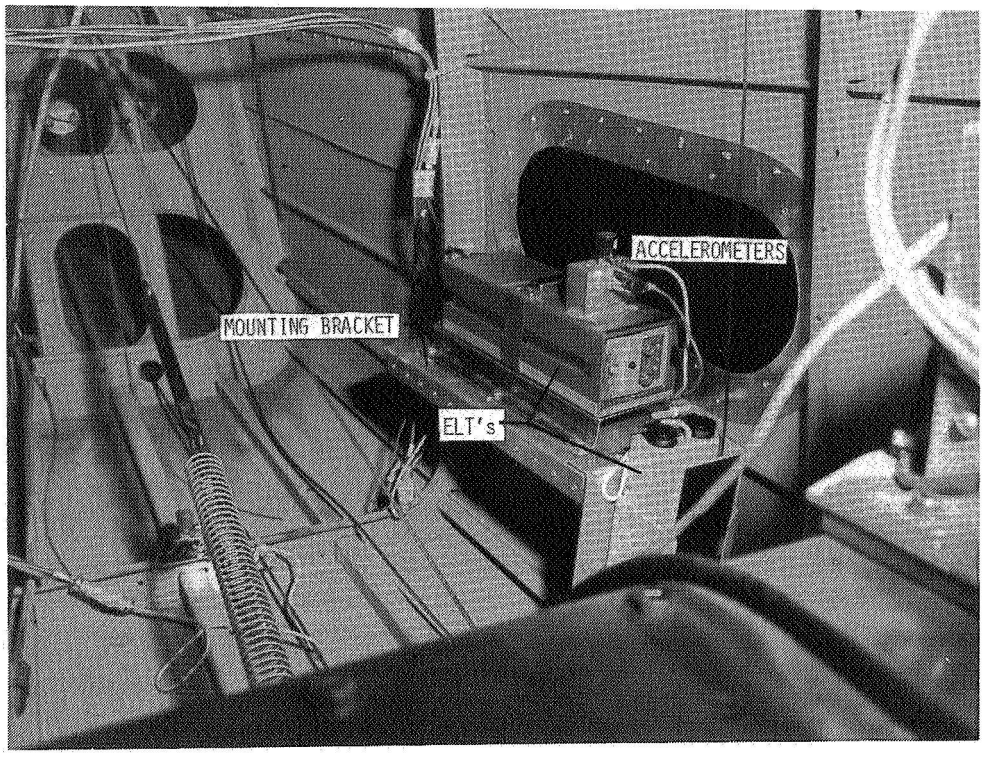


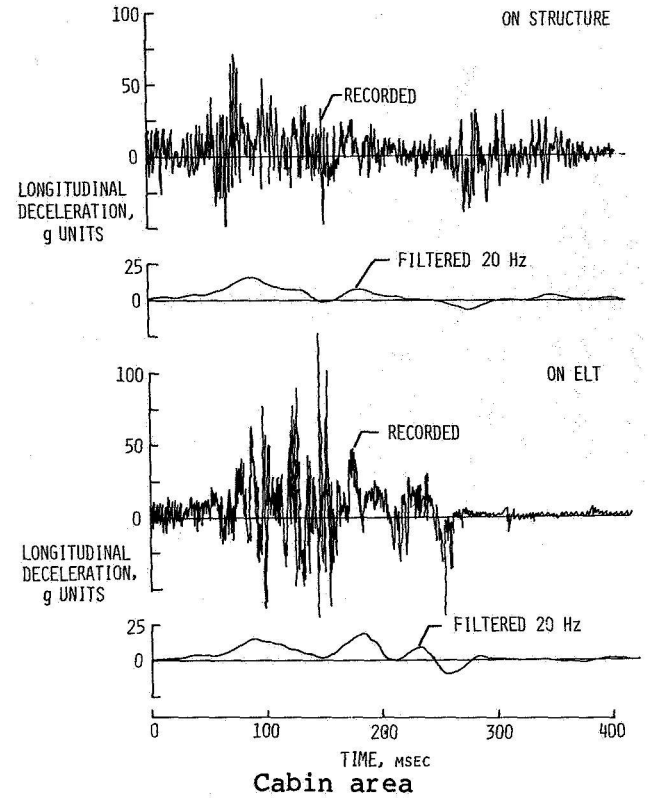
Figure 8.- Switch vibration apparatus.

(a) Cabin area.

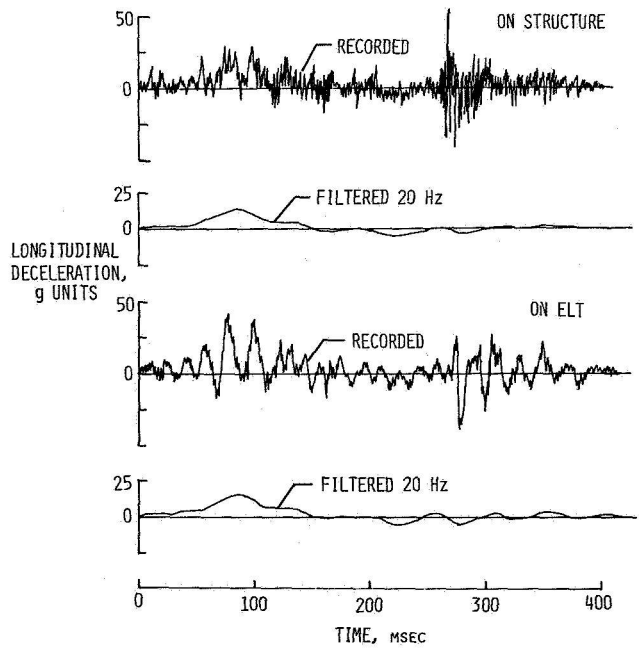


(b) Tail cone area.

Figure 9.- ELT's mounted in test airplane for crash tests.



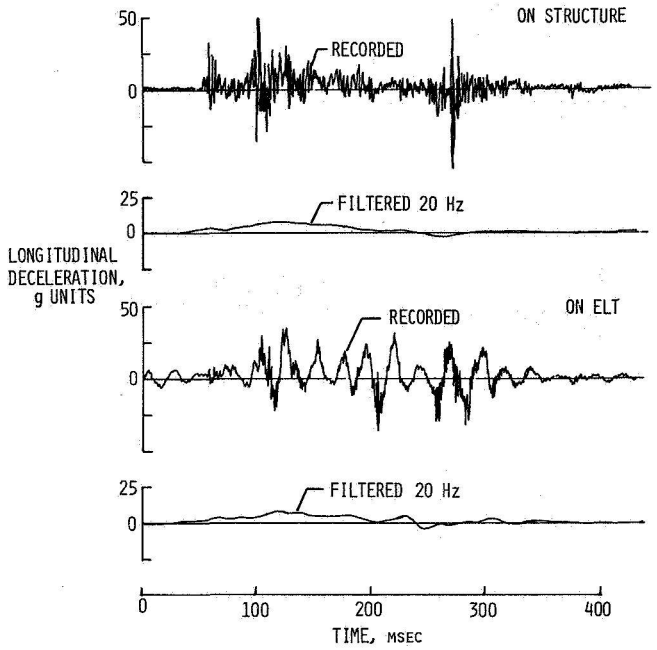
Cabin area



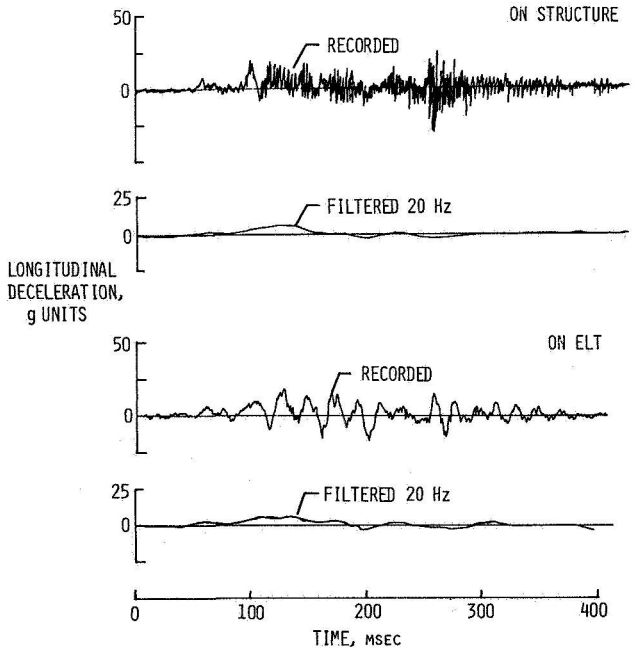
Tail cone area

(a) Flight path, -30°; pitch angle, -30°.

Figure 10.- Longitudinal decelerations in crash test airplane. Velocity, 27 m/sec (60 mph).



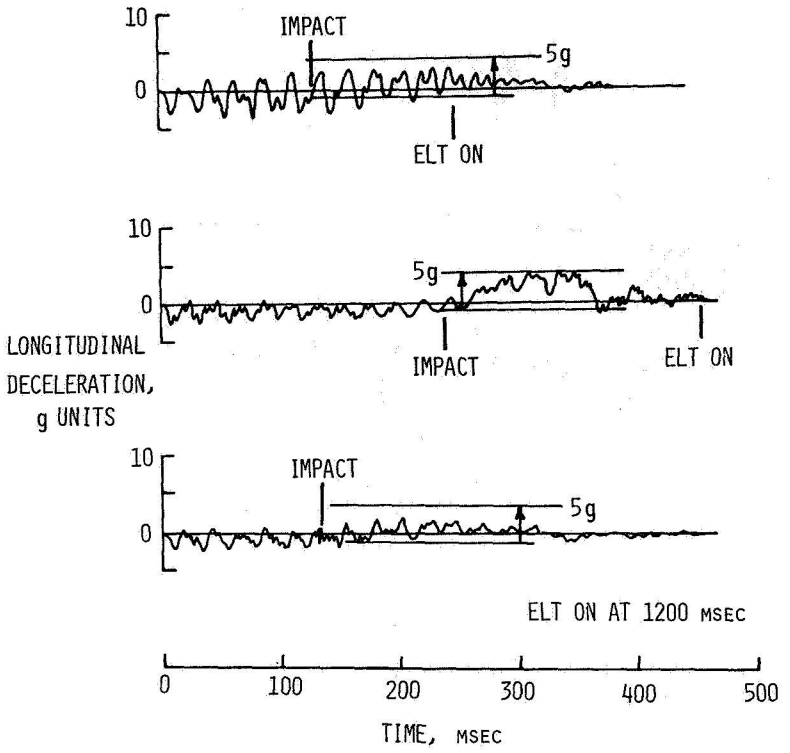
Cabin area



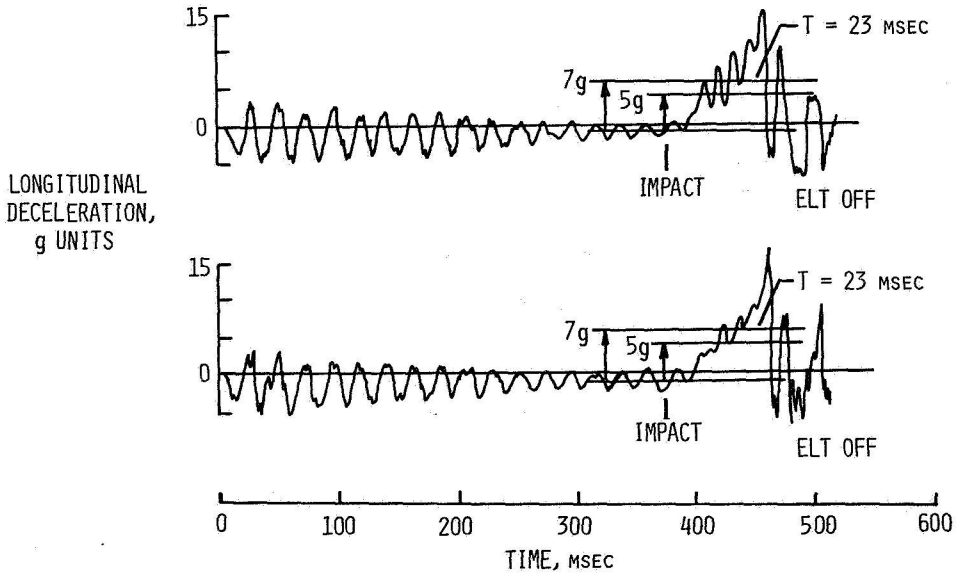
Tail cone area

(b) Flight path, -15°; pitch angle, -15°.

Figure 10.- Concluded.

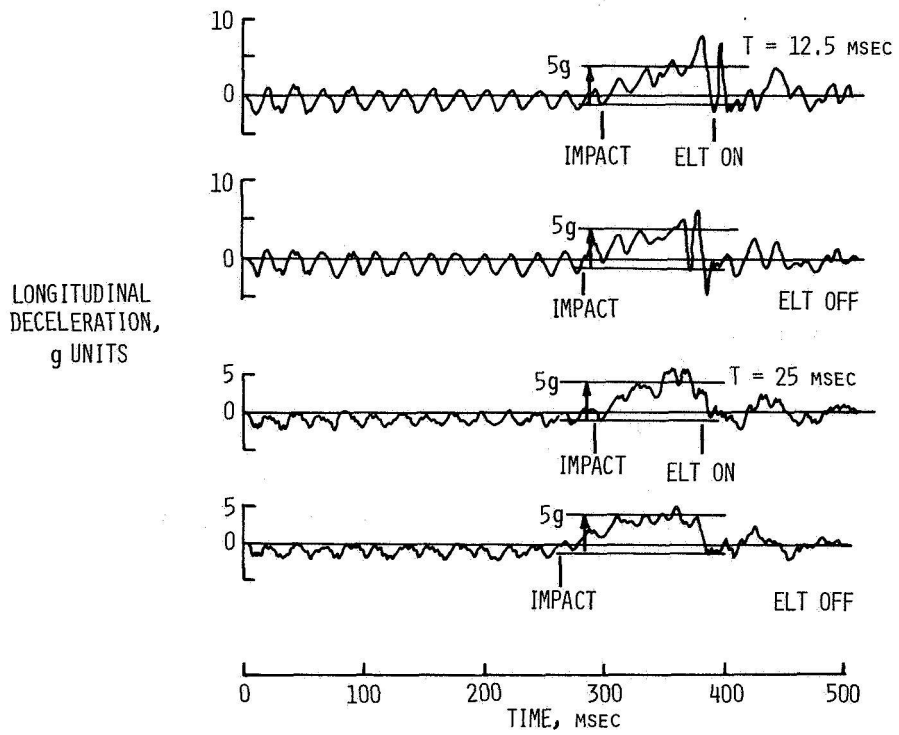


(a) Out of specifications - below threshold.



(b) Out of specifications - above threshold.

Figure 11.- Typical laboratory impact test results on ELT activation.



(c) Within specifications.

Figure 11.- Concluded.

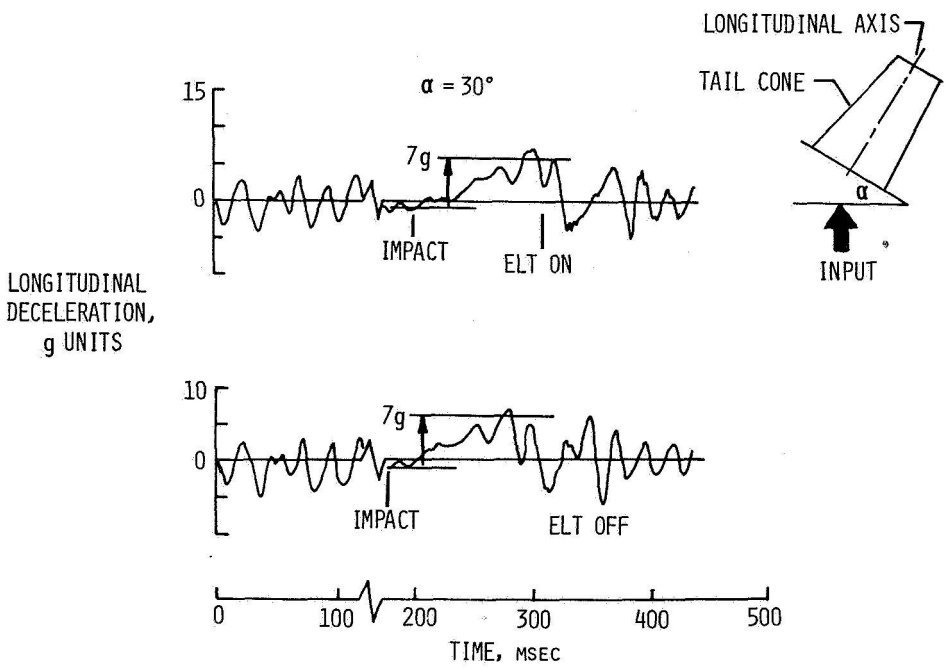


Figure 12.- Off-axis impact results.

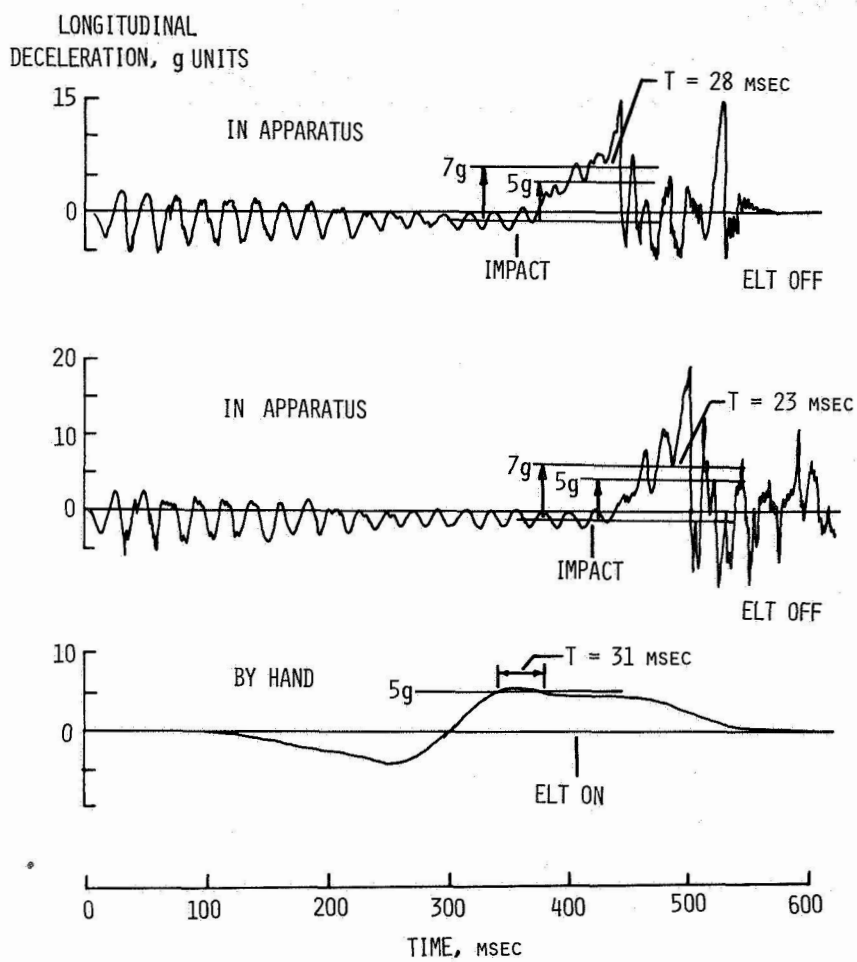
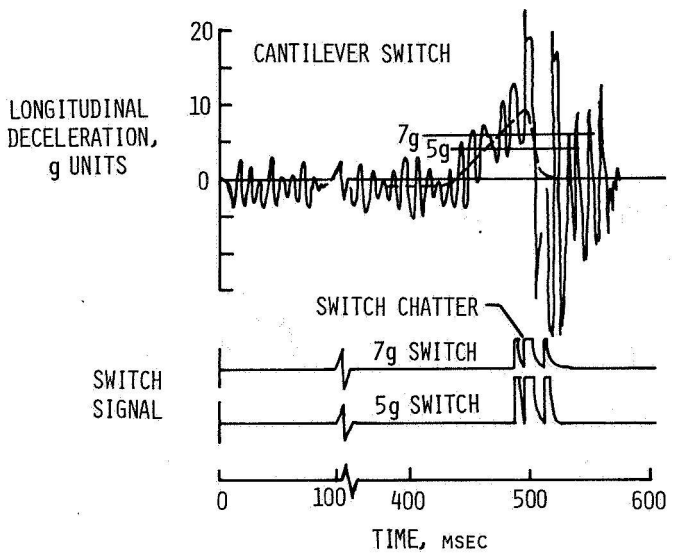
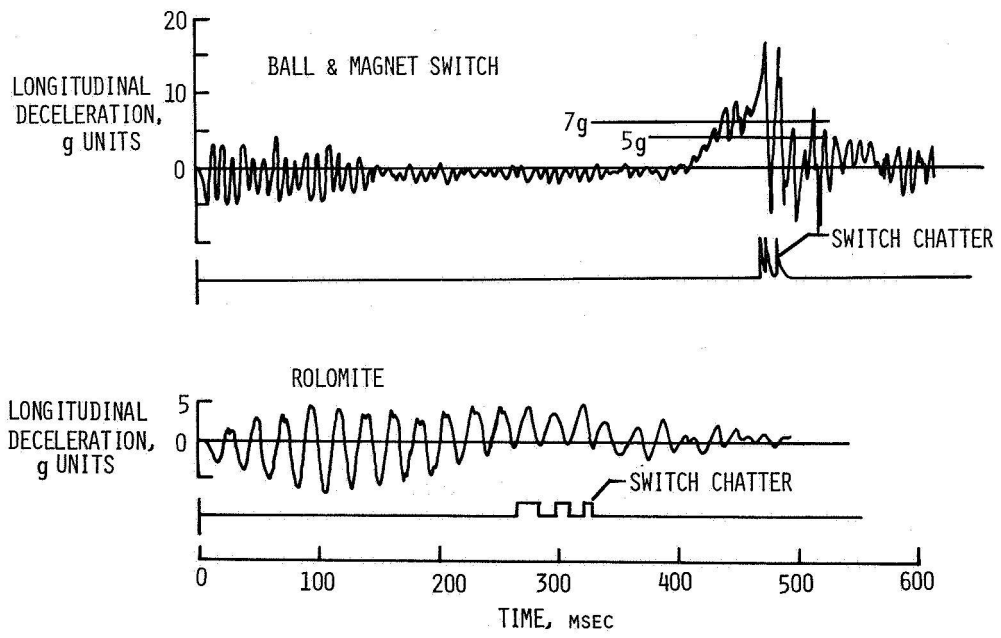


Figure 13.- Anomalous ELT activation behavior.

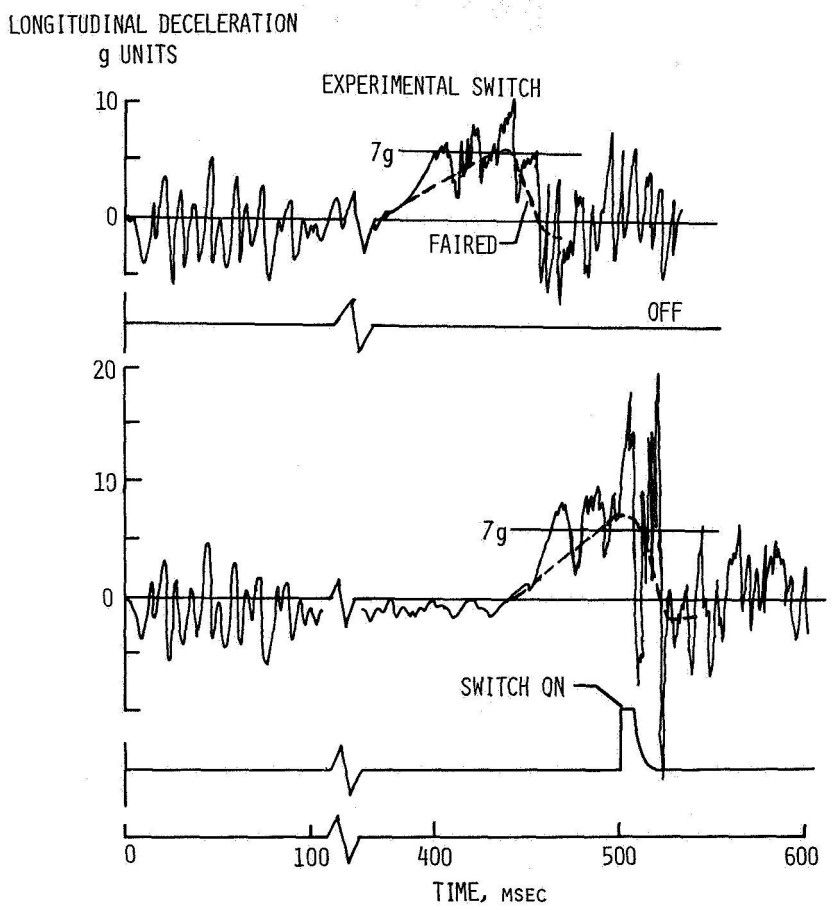


(a) Cantilever beam switch.



(b) Ball and magnet and rolomite switches.

Figure 14.- Inertia switch chatter during impact tests.



(c) Experimental low-frequency switch.

Figure 14.- Concluded.

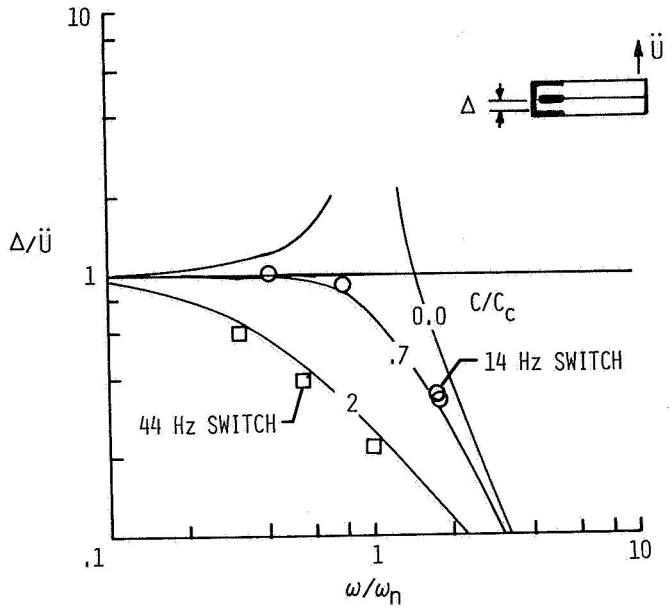


Figure 15.- Sinusoidal vibration test results for ELT switches.

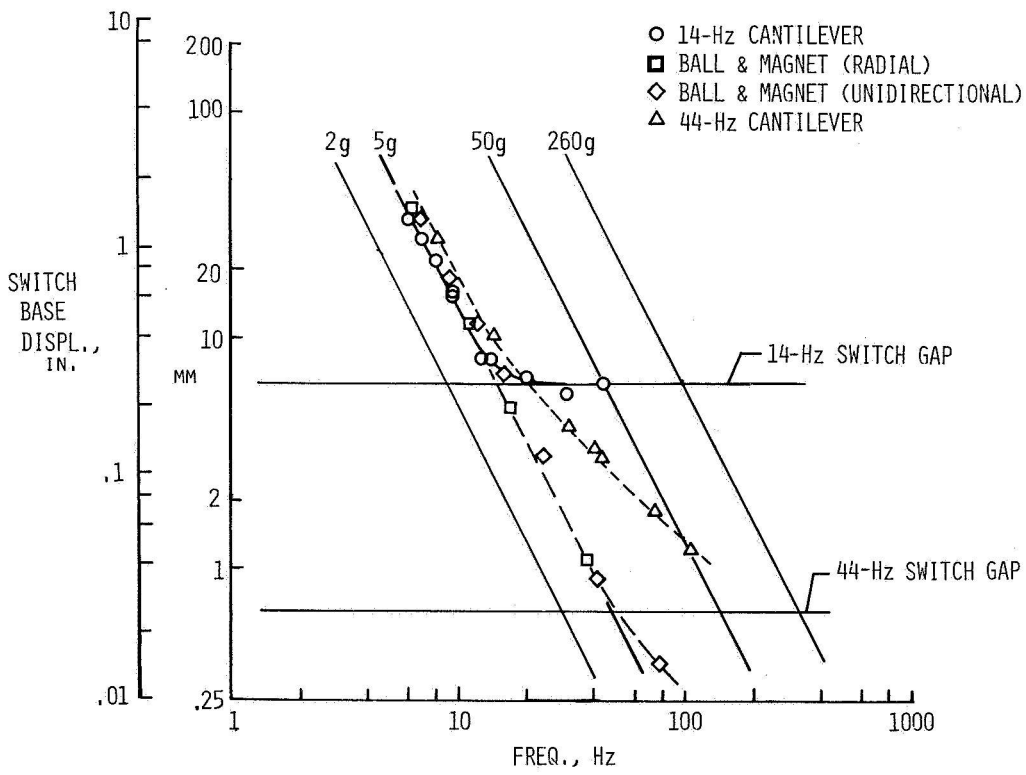


Figure 16.- ELT switch vibration displacement as a function of excitation frequency.