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Development of a Crashworthy Seat for Commuter Aircraft

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September 1990

Final Report

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16. Abstract

A series of dynamic impact tests were conducted using a prototype seat with an energy absorbing mechanism as part of the seat pan. The seat frame was designed to represent a typical commuter aircraft passenger seat. Tests were conducted in an orientation simulating a vertical impact with a 30-degree nose-down aircraft attitude. The impact severity for these tests ranged from 15 to 33 Gs. Seat pan stroke and occupant lumbar reaction forces were measured. Results indicate the axial force measured in the lumbar spine of a fiftieth percentile Hybrid II dummy can be limited to a peak value less than 1500 pounds during vertical impact tests of 33 G with a seat pan stroke distance of 6.3 inches.

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DEVELOPMENT OF A CRASHWORTHY SEAT FOR COMMUTER AIRCRAFT

INTRODUCTION

Crashworthy seat requirements in the Federal Aviation Regulations (FARs) were amended in 1988 and 1989 for aircraft defined in FAR Parts 23, 25, 27, and 29 (1,2,3,4*). Each of these regulations contains a pass-fail criterion for a vertical test condition, which states the "maximum compressive load measured between the pelvis and the lumbar column of the anthropomorphic dummy (ATD) must not exceed 1500 pounds." Dynamic tests for seats in normal, utility, and acrobatic aircraft as defined in Part 23 include a test condition that represents a vertical impact with the pitch axis of the aircraft oriented in a 30-degree nose-down configuration. The dynamics of the impact test specify the velocity must be 31 feet per second (ft/sec) with a peak deceleration of 19 Gs for pilot seats or 15 Gs for passenger seats. Requirements in Part 25 of the FARs for seats in transport category aircraft contain a test in the same vertical impact orientation with the impact velocity of 35 ft/sec and a peak deceleration of 14 Gs. Rotorcraft seat performance requirements in Parts 27 and 29 specify the same vertical impact test orientation with a velocity of 30 ft/sec and a peak deceleration of 30 Gs.

Dynamic impact test programs conducted at the Federal Aviation Administration's (FAA) Civil Aeromedical Institute (CAMI), have evaluated various techniques to meet the pelvic load requirement with seats developed for Parts 23 and 25 categories of aircraft as well as military rotorcraft (5,6). Based on the results of these tests, three of the main factors that influence the pelvic load response are: (a) the deceleration pulse severity, (b) the energy absorbing (EA) properties of the vertical load paths through the cushion, seat pan, and seat legs, and (c) the available clearance for unimpeded deformation or controlled stroking beneath the seat pan. Part 25 aircraft seats (passenger, pilot, and crew) have met the 14 Gs requirement with "passive EA" components such as a dense foam cushion on a sheet metal seat pan with two inches of clearance beneath the pan. Passenger seats for FAR Part 23 have passed the 15 Gs vertical test by incorporating a dense foam cushion and deformable or flexible seat pan with three inches of free space beneath the pan. Part 23 pilot seats have met the 19 Gs requirement with designs that included energy absorbing cushions/seat pans and "active EA" components such as curved legs that attenuate vertical forces by bending or stroking downward three to four inches (5). In comparison, military rotorcraft pilot seats designed to meet the 50 Gs vertical impact test specification of MIL-S-58095 (7,8) require elaborate energy absorbing mechanisms with as much as 14 inches of vertical stroke capability. Thus, seats tested at a higher severity than the 15 Gs condition for Part 23 passenger seats have required vertical-displacement active EA components that limit the forces reacted at the seat pan in order to enable it to pass the pelvic load specification.

Commuter Aircraft Seats

Commuter aircraft are categorized as those with 19 passenger places and weighing 19,000 pounds. Although the airworthiness standards for commuter aircraft are currently provided in FAR Part 23, the size and flight performance characteristics of commuter airplanes are in most cases different from the characteristics of smaller aircraft (weighing less than 12,500 pounds with seating capacity of nine passengers or less) also regulated in Part 23. Concerns have been raised within the FAA to address the vertical test severity for commuter seats as a separate requirement from the Part 23 regulations adopted in 1988. Analysis of commuter accidents and ongoing research may determine the need to change the vertical impact test severity for commuter aircraft, on the basis of higher crash loads experienced by occupants in a commuter aircraft. One proposal for a commuter seat vertical test condition is a 32 Gs peak triangular deceleration pulse with a rise time of 0.030 seconds and an impact velocity of 32 ft/sec. The deceleration pulse shape for this impact condition is shown in Figure 1, along with the three vertical test pulses defined in the FARs.

Based on the results from dynamic tests of seats developed to pass existing impact requirements, a commuter seat that will meet the pelvic force criteria when subjected to a 32 Gs vertical

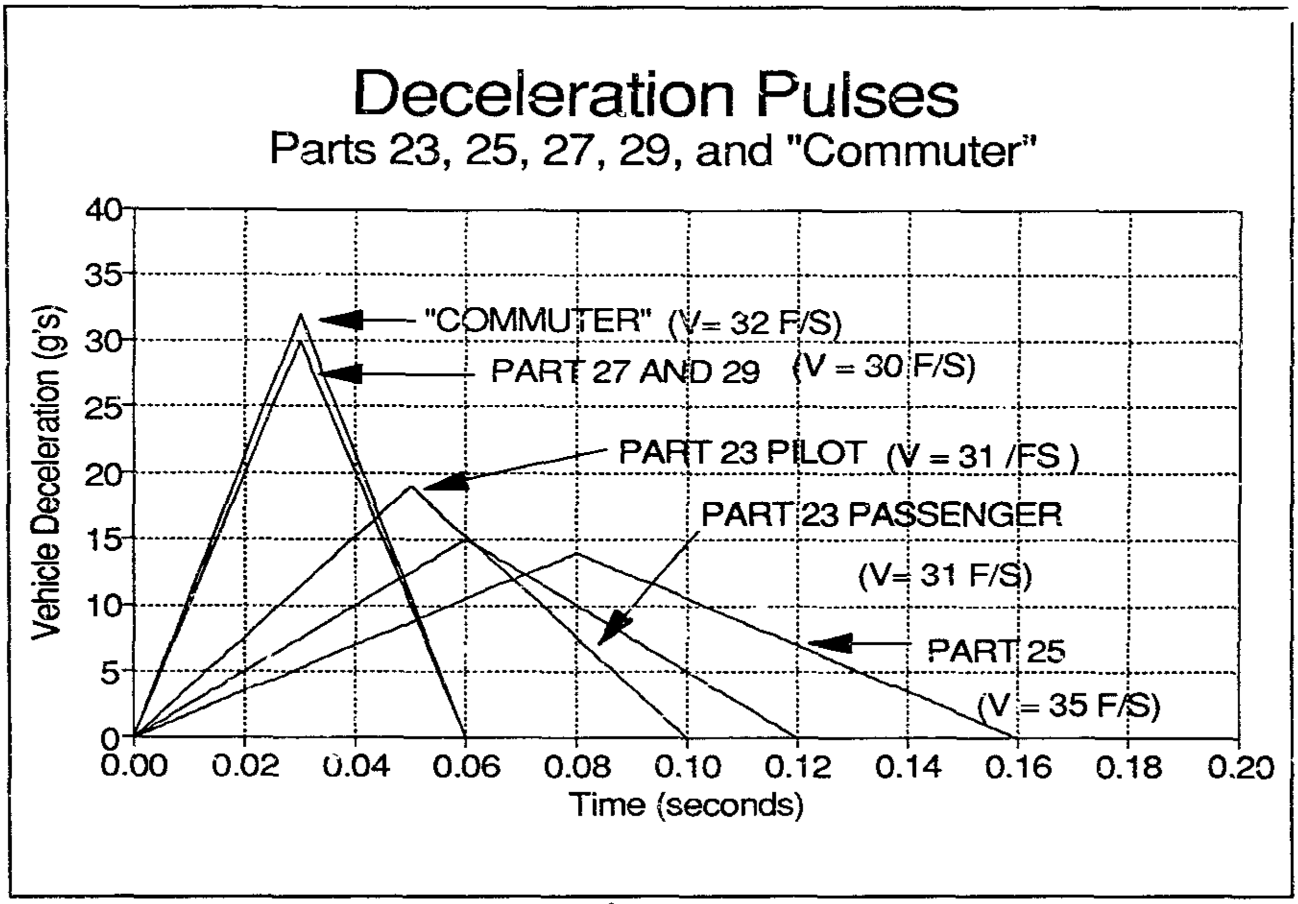

Figure 1

test condition will require an active energy absorbing system to attenuate vertical forces in the seat pan. The design of the EA seat system should be optimized to limit the dynamic peak response the pelvic load of the ATD and function within the physical constraints of the aircraft interior. The load properties of the EA system must provide a force-limiting system that will effect a peak response of less than 1500 pounds in the pelvic load cell, and the resulting deflection (or stroke) must be limited to the volume of space beneath the seat pan in the aircraft installation.

A common characteristic of many commuter airplane passenger seats is the limited available space beneath the seat pan. Seats may be attached to the wall of the cabin interior with less than six inches of vertical clearance between the outboard seat pan frame and the curved interior wall of the fuselage. Others may be positioned with the seat pan directly over raised sections of the cabin floor with very limited clearance beneath the pan. A crashworthy commuter seat developed to meet the suggested 32 Gs severity must be designed with consideration for the amount of vertical deflection of the seat pan.

The CAMI Seat Pan

To investigate the dynamic load-deflection properties of an EA seat intended to provide a 32 Gs vertical impact load injury protection, a research program was initiated in 1989 by CAMI's Biodynamics Research Section, with participation from members of the General Aviation Manufacturers Association (GAMA). Tests conducted with current production seats were not successful in meeting the Part 23 vertical test requirements, and attempts to modify the production seats did not produce satisfactory results. To meet the project goal of a satisfactory "32 Gs seat," a seat frame was constructed at CAMI to function as a test fixture for the development of an EA seat pan system.

The components of the CAMI seat, shown in Figure 2, were not modeled after a particular production seat; rather, the base frame was designed to accommodate an EA system and

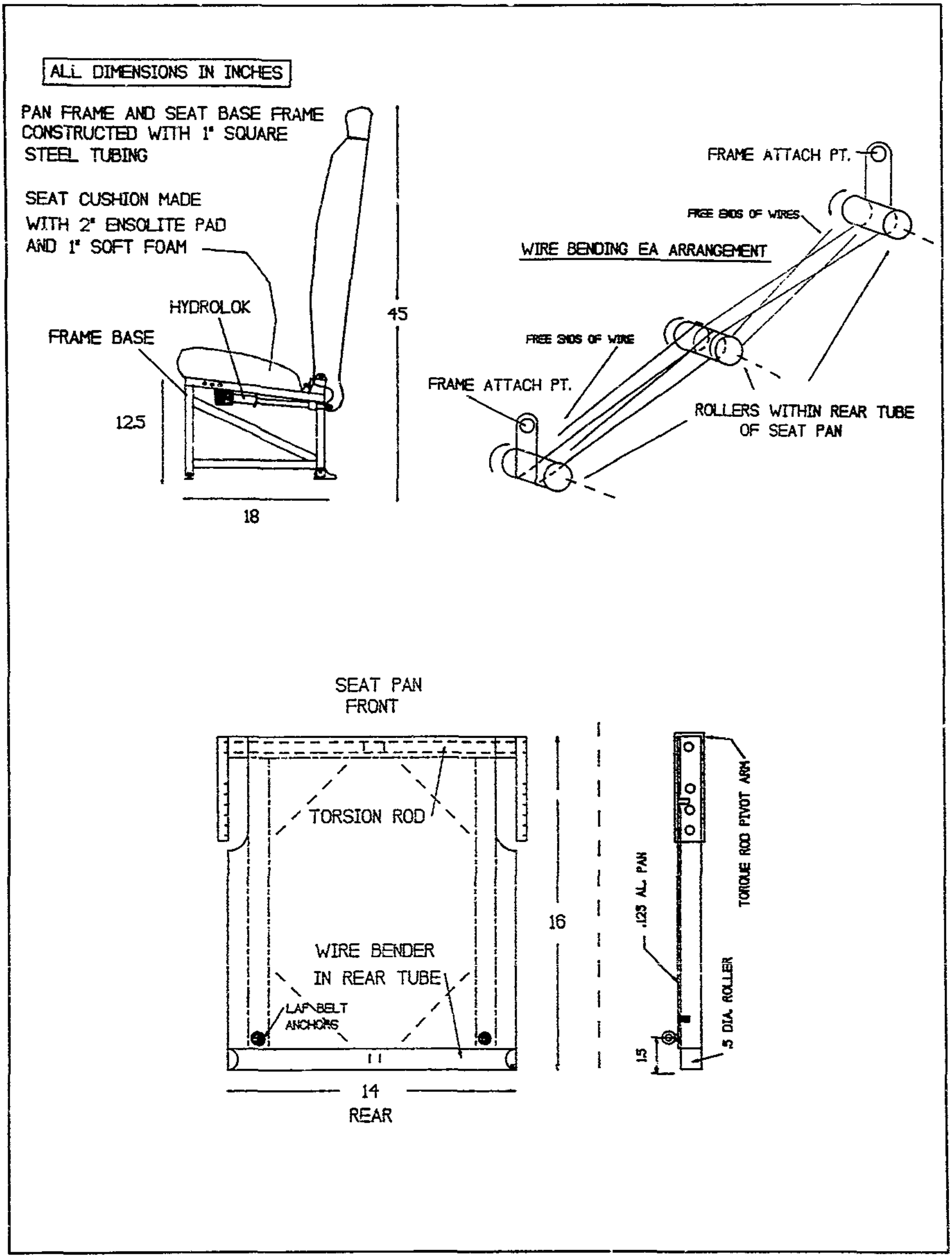
ALL DIMENSIONS IN INCHES
PAN FRAME AND SEAT BASE FRAME CONSTRUCTED WITH 1" SQUARE STEEL TUBING
SEAT CUSHION MADE WITH 2" ENSOLITE PAD AND 1" SOFT FOAM
HYDROLOK
FRAME BASE
45
12.5
18
FRAME ATTACH PT.
FREE ENDS OF WIRES
WIRE BENDING EA ARRANGEMENT
FREE ENDS OF WIRE
FRAME ATTACH PT.
ROLLERS WITHIN REAR TUBE OF SEAT PAN
SEAT PAN
FRONT
TORSION ROD
WIRE BENDER
IN REAR TUBE
LAP BELT ANCHORS
16
14
REAR
.125 AL PAN
TORQUE ROD PIVOT ARM
.5 DIA. ROLLER
1.5

Figure 2

provide adequate dimensions and strength to evaluate a range of impact conditions. A seat back and three-point restraint system were obtained from a salvaged passenger seat for a small aircraft. The seat cushion was constructed with a two inch thick layer of Ensolite beneath a one inch pad of soft foam.

The EA system chosen for this project was a dual mechanism design. A torsional EA device supported the front of the seat pan and was connected to the seat base frame by pivot arms at each side of the front of the pan. A wire bending EA device linked the rear corners of the seat pan to the base frame. These EA mechanisms were chosen because they were simple to construct with commonly stocked materials. The seat pan diaphragm was a rigid aluminum plate. Although no detailed engineering design or modeling analysis was performed, laboratory experience with similar devices provided a rational basis with which to evaluate these devices. The torsional EA was comprised of a square steel rod secured by a fixed guide in the center of the front tube of the seat pan. The ends of the steel rod attach to the pivot arms connected to the base frame. As vertical forces are reacted at the front of the seat pan, the pivot arms rotate downward, twisting the steel rod between the center guide block and the pivot arms on either end. The wire bending EA device on the rear of the seat pan consists of a pair of wire loops routed over rollers within the rear tube of the seat pan. The left and right wires are placed over a common roller in the center of the rear tube, and each wire exits the rear tube over a roller on each end; from there the loop on each wire passes through a shackle attached to the upper rear corner of the base frame. Vertical forces reacted at the rear of the seat pan pull the wires through the path over rollers, bending each wire around the radius of the rollers. As the wires are pulled through the rollers, the seat pan moves downward. The force to maintain the wire bending action is constant and may be altered by the type and size of wires installed.

The variables that could affect the force-deflection parameters of the system were: (a) the size of the torsion rod on the front of the seat pan, (b) the diameter and material of the wires in the wire bending mechanism, (c) the angle of the seat pan (adjusted by the pivot arms attachment), and (d) the seat cushion. Various combinations of torsion rod and wire sizes were evaluated during the trial tests with this seat pan. The best performance was achieved with a 0.375 inch square torsion bar in combination with .092 inch diameter welding rod for the wire bender. Static load deflection curves for this arrangement are shown in Figures 3 and 4.

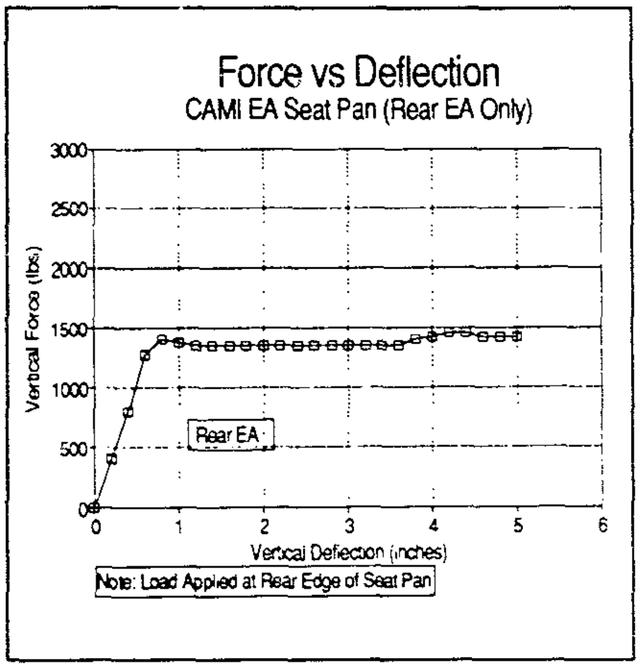

Figure 3

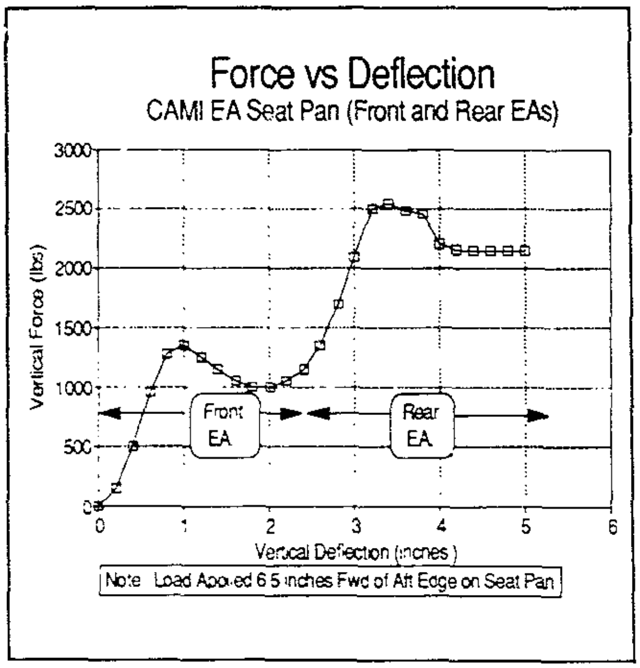

Figure 4

The force required to stroke the wire bending EA was approximately 1400 pounds with the load applied at the aft edge of the seat pan. With a static force applied at a point 6.5 inches forward of the aft edge of the seat pan, the force deflection curve for the seat pan exhibits a two step action. An initial plateau occurs at around 1200 pounds for the first two inches of pan stroke as the torsional EA activates, allowing the front of the pan to rotate down. Then the wire bending EA starts stroking and a second force plateau at approximately 2200 pounds is maintained as the static load point moves vertically beyond 3.5 inches for the remaining seat pan stroke. Since the initial pitch of the seat pan was about 20 degrees above horizontal, the vertical displacement of the front edge of the pan was not considered to be as significant as the rear edge movement into the volume within the seat base frame.

Dynamic Tests

Dynamic impact tests of the CAMI EA seat were conducted on the CAMI impact track. Figure 5 shows the impact sled setup with this seat for the vertical impact test specified in the FARs and proposed for commuter seats. This facility uses a horizontal deceleration system to implement controlled impact tests. The sled is accelerated to the desired velocity on parallel circular rails using a cable and pulley system attached to a falling weight. The tension in the cable becomes slack as the sled nears the brake device, which consists of a set of 0.235 inch diameter steel wires placed across the track rails. As the sled coasts at a constant velocity into contact with the wires in the brake, the wires are pulled through rollers fixed on each side of the track. The action of pulling the brake wires through the rollers creates a deceleration force; and the deceleration pulse shape is controlled by the number, spacing, and length of wires placed in the brake. The pitched fixture, shown in Figure 5, positioned the seat in a 30 degrees nose down orientation relative to the velocity and deceleration vector of the sled. A fiftieth percentile Hybrid II ATD was used as the occupant.

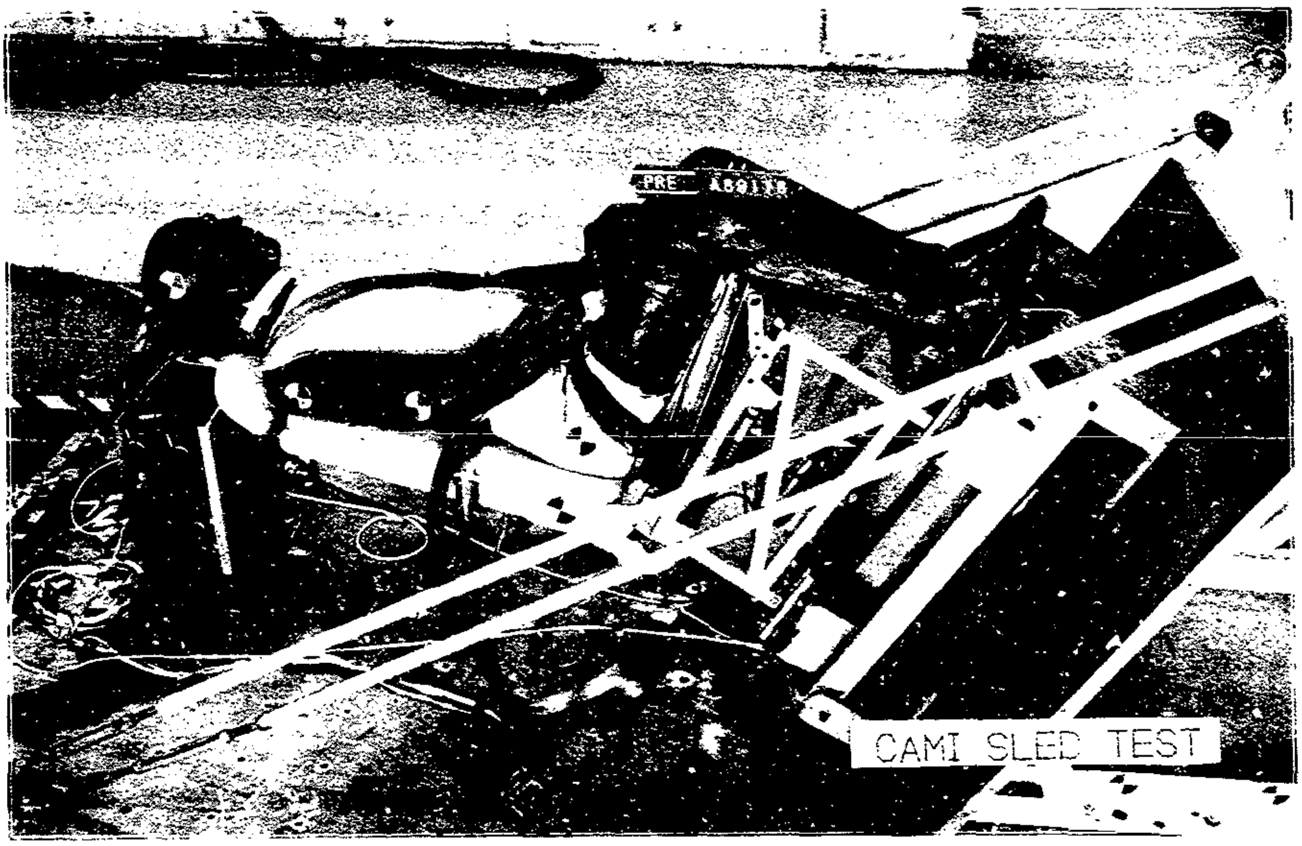

Figure 5

TEST NUMBER	PEAK SLED X (Gs)	AVERAGE SLED X (Gs)	VELOCITY (f/s)	PELVIC FZ (lbs.)	SEAT PAN STROKE (inches)
A89116	33.4	19.1	31.0	1371	6.3
A89156	15.6	8.4	8.4	826	1.0
A89157	21.8	14.5	14.5	1093	3.5
A89159	24.8	11.8	11.8	1178	2.4

Table 1

Table 1 lists four of the tests conducted with this seat. Figures 6, 7, and 8 present the pertinent data acquired during the impact tests. Test A89116 was conducted with a peak deceleration of 33 Gs and a velocity of 31 ft/sec. The peak pelvic compressive force measured 1371 pounds, and the rear edge of the seat pan stroked 6.3 inches downward. The motion of the seat pan during the impact resembled the sequence that occurred during the static force-deflection test. First, the torsional EA activated, allowing the front of the seat pan to rotate down approximately 3 inches, followed by the wire bending EA action as the rear of the seat pan moved down 6.3 inches. This sequence of actions by the front and rear EAs resulted in a rotational motion by the seat pan. The front edge rotated through an arc with a radius defined by the pivot arms on

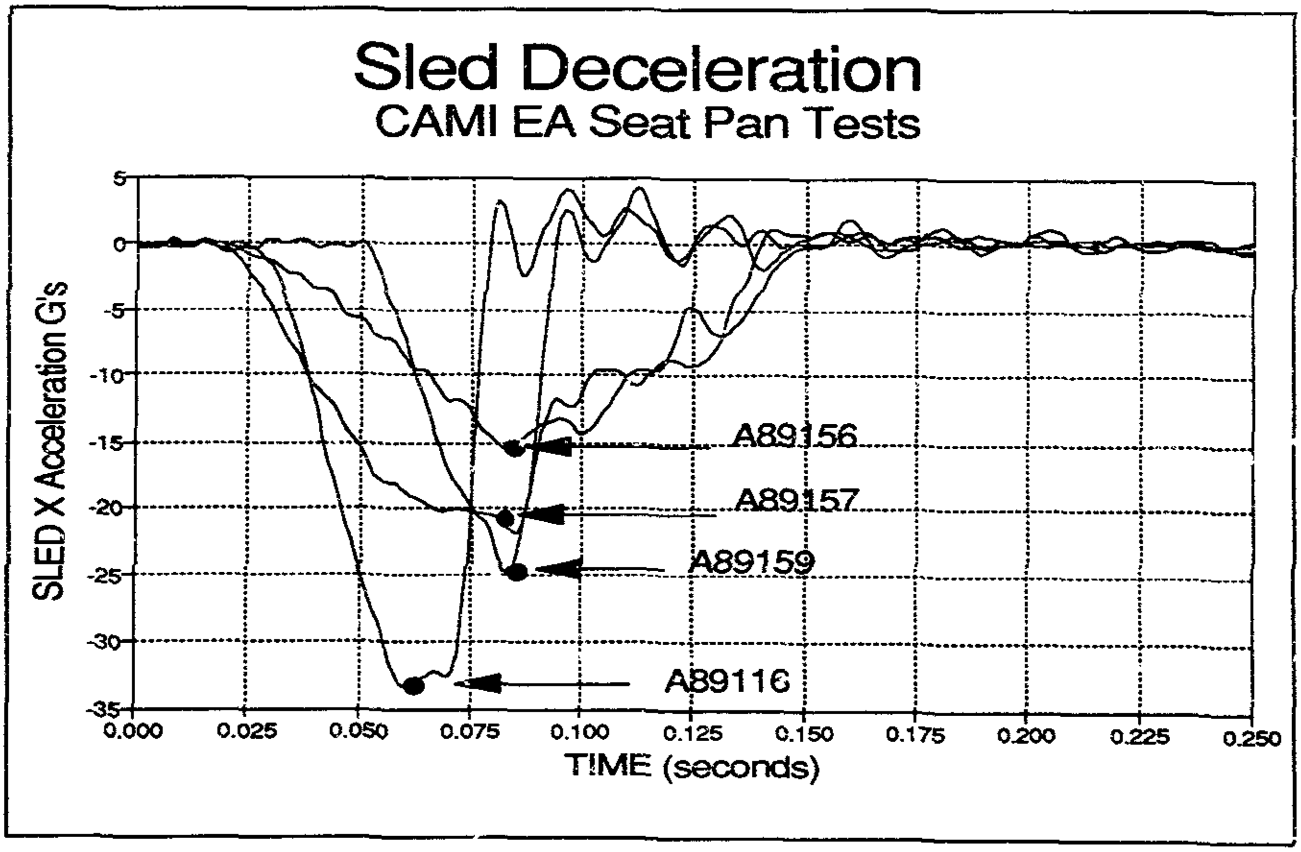

Figure 6

the front of the pan. Then, the rear edge rotated about the axis of the torsion rod. The peak pelvic force responses from the other three tests listed in Table 1 were all within the 1500 pound limit, and the vertical stroke distance of the seat pan rear edge ranged from 1.0 to 3.5 inches. As expected, the amount of seat pan stroke decreased as the severity of the impact decreased. In each test the same sequence of EA actions occurred: the front EA activated first; then the wire bender started to stroke.

Because these were not pure vertical tests, the horizontal component of deceleration resulted in a slight forward translation of the ATD. It was important to keep the ATD in the normal position over the cushion because the rear EA effectiveness decreases as the vertical load transmitted to the seat pan moves forward. The lap belts were attached to the seat pan to limit forward movement of the ATD's pelvic section during seat pan stroking action. Attachment of the lap belts to the seat pan was also required to maintain the proper belt path over the pelvis.

RESULTS AND DISCUSSION

Tests A89156 and A89157 were conducted with impact conditions conforming to the requirement for FAR Part 23 passenger and pilot seats respectively. The same EA size wire and torsion rod, as used in test A89116, were installed for these tests. Test A89159 was conducted with a peak deceleration of 24.8 Gs to obtain data from an impact severity between the 19 Gs of test A89156 and the 32 Gs of test A89116.

As shown in Figure 8, the seat pan vertical displacement during test A89157 was more than the displacement recorded during the higher peak deceleration in test A89159. This may be due to the sled deceleration pulse shapes achieved in these two tests. Figure 6 shows the Sled X pulse from A89157 had a rounded peak with a .040 second plateau at the level of 20 Gs. The Sled X pulse from A89159 had a shorter duration peak around 25 Gs and rapid post-peak decay.

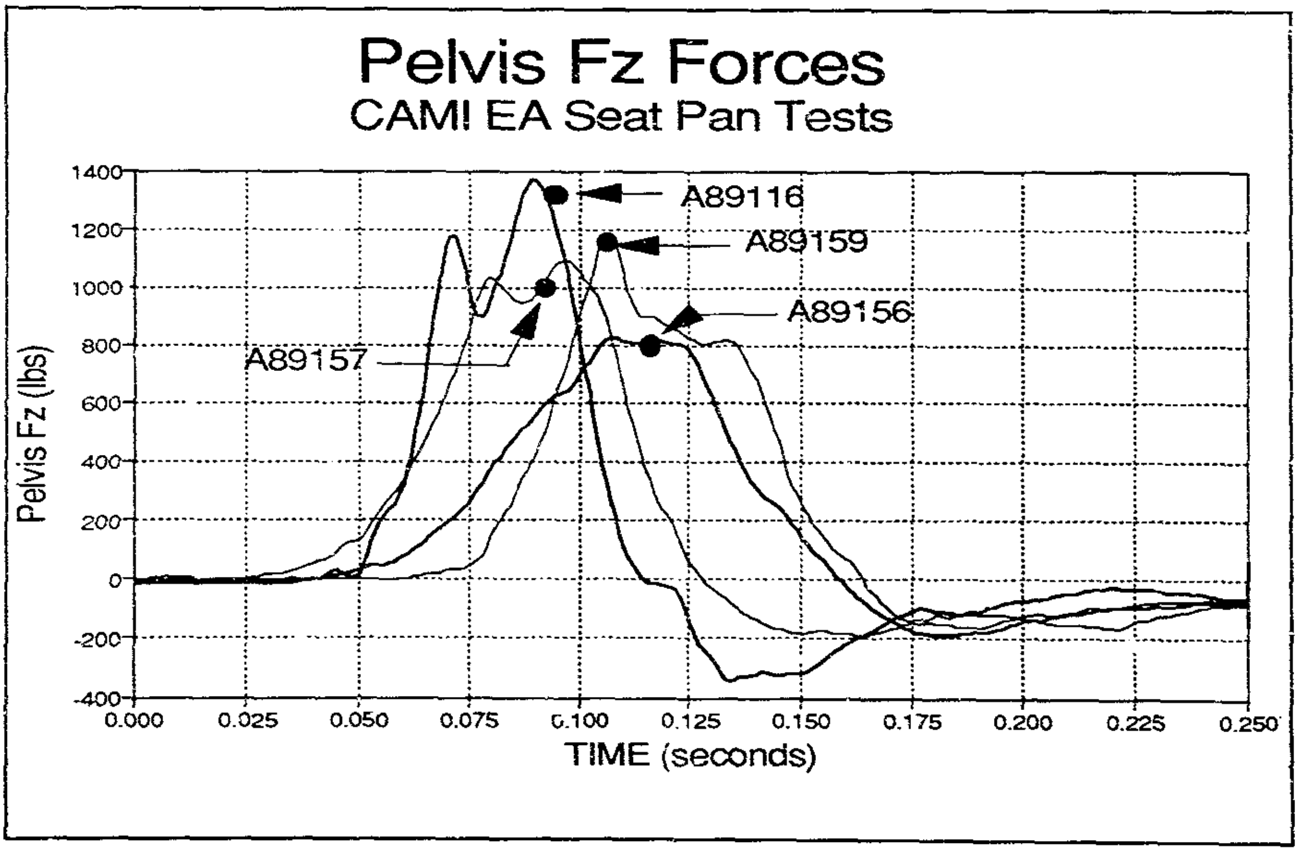

Figure 7

The relationship between seat pan stroke and deceleration pulse shape for these tests can be demonstrated by analyzing the time period for the energy applied to the system. These tests were conducted with approximately the same sled velocity; therefore, the total energy dissipated by the seat/occupant test specimens was similar. As the peak Gs of the triangular shaped Sled X pulse increased, the time period of the pulse decreased. The Sled X pulses achieved during these tests were not perfectly symmetrical triangles; therefore, the average rate at which the energy was dissipated during the impact interval was calculated by using the following equation:

$$AER = ((G_{avg} \times T)^2 / 2) / T$$

AER = Average Energy Rate
T = Period of Deceleration (sec.)

Figure 9 shows the relationship between this calculated energy dissipation rate and the seat pan vertical displacement for these four tests. The calculated average energy rates for tests A89116 and A89156 were the upper and lower bounds, as shown. Note the average energy rate for test A89159 is less than the rate calculated for test A89157, even though the peak sled deceleration from test A89159 is greater. This supports the qualitative analysis of pulse shape differences discussed above. Thus, average energy rate was a significant factor in the performance of the seat pan tested in this series.

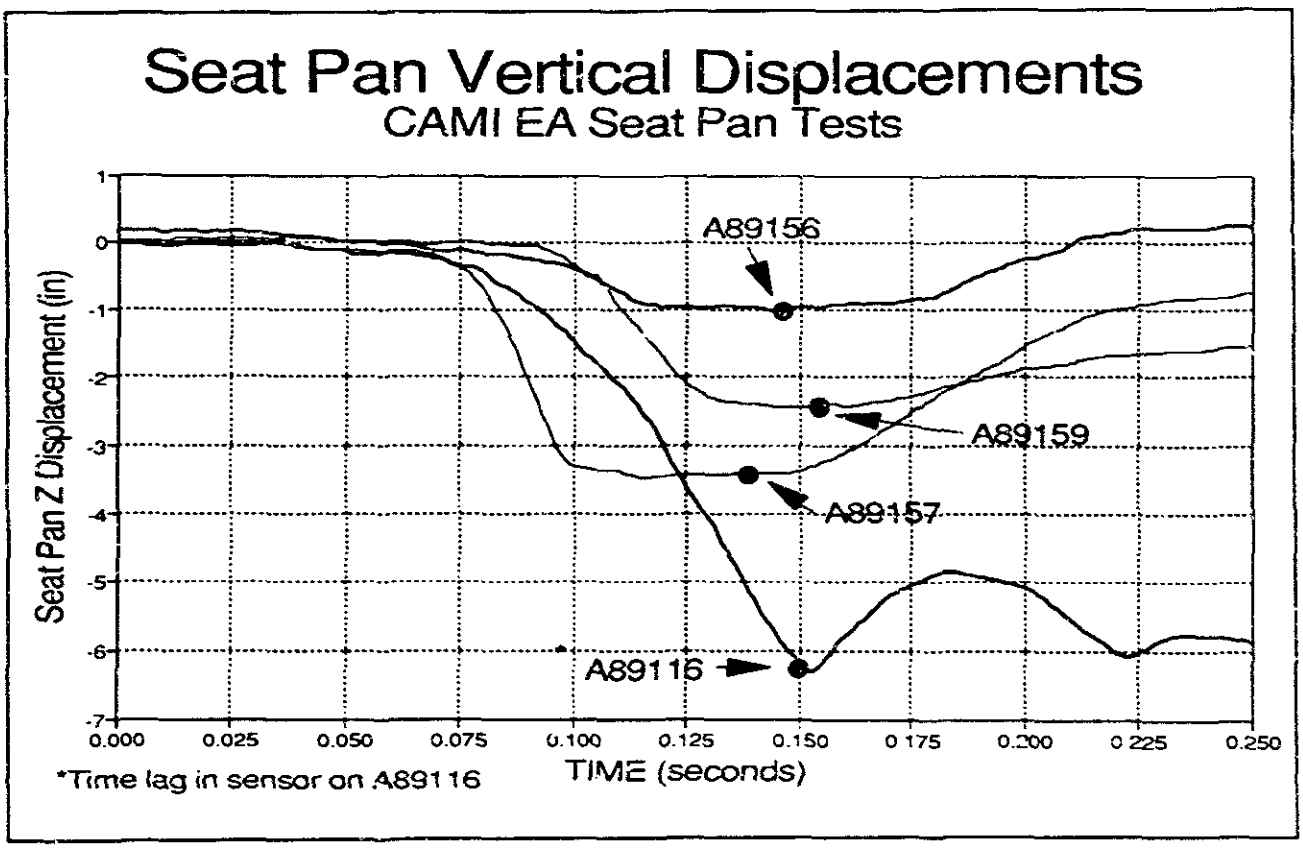

Figure 8

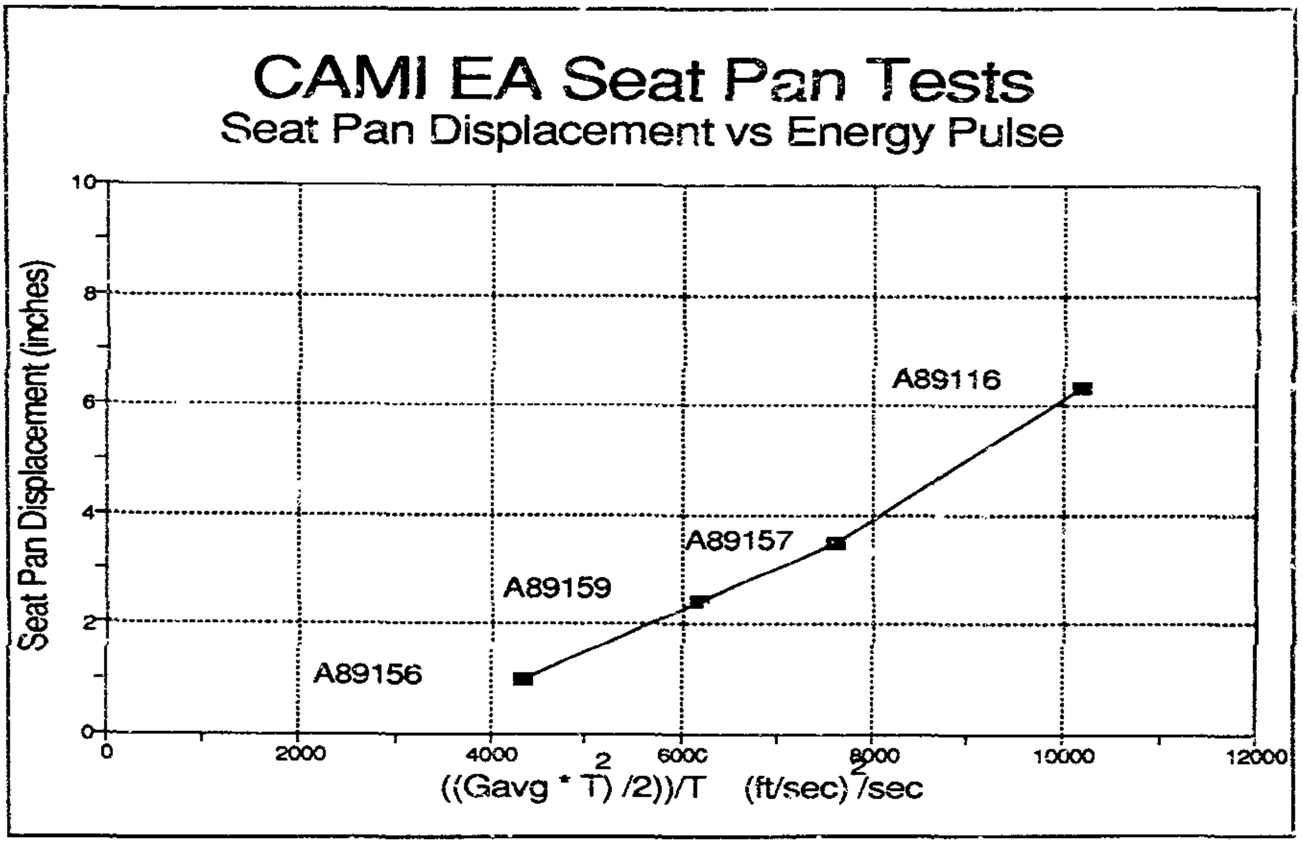

Figure 9

CONCLUSIONS

1. The maximum seat pan vertical displacement was 6.3 inches during the 32 Gs impact with this seat pan design. It should not be inferred that this dimension is to be used as a design factor. Rather, the vertical displacement can be as much as 6.3 inches with EA systems *that perform in a similar manner. If commuter* seats are to be developed to meet a 32 Gs vertical impact test condition, the volume available for seat pan stroke into the space beneath the seat pan should conform to the dynamic deflection characteristics of the EA system.

2. Seat pan performance, as measured by stroking distance and peak pelvic force, is sensitive to pulse shape. The peak deceleration Gs of an impact test are not necessarily the primary indicator of the test severity. Impact test facilities can only approximate an ideal pulse shape. Therefore, a careful definition of an acceptable pulse shape or a method to measure pulse severity should be addressed if further research or regulatory activities occur.

3. The results from the dynamic tests with this seat indicate the need for an active energy absorbing system in order to meet the pelvic load criterion when a seat is subjected to the vertical *test orientation of the FARs at a pulse severity* 32 Gs and an impact velocity of 32 ft/sec. This project did demonstrate a EA seat pan can be constructed with common materials and perform satisfactorily during impact conditions ranging from 15 to 32 Gs.

4. The EA system developed for this project may not provide optimal performance, and other systems may be capable of meeting the injury criterion with greater efficiency. One feature that might enhance the performance of the system would be a deformable seat pan diaphragm, that absorbs some of the vertical energy.

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