# DEVELOPMENT OF AN ENERGY-ABSORBING PASSENGER SEAT FOR A TRANSPORT AIRCRAFT

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## INTRODUCTION

Commercial air transport passenger safety and survivability, in the event of an impact-survivable crash, are subjects receiving increased technical focus/study by the aviation community. One such study was recently initiated by a joint understanding of the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA). A B-720 aircraft, highly instrumented, and remotely controlled from the ground by a pilot in a simulated cockpit, was crashed on a specially prepared gravel-covered impact site. The aircraft was impacted under controlled conditions in an air-to-ground gear-up mode, at a nominal speed of 150 knots and 4-1/2° glide slope. The flight test was performed at the NASA Ames Dryden Flight Research Facility at Edwards Air Force Base, California.

Data from a number of on-board, crash-worthiness experiments provided valuable information related to structural loads/failure modes, artimisting kerosene fuel, passenger and attendant restraint systems and energy-absorbing seats. This paper describes the development of an energy-absorbing (EA) seat accomplished through innovative modification of a typical modern-standard, commercial aviation transport, three-passenger seat. Values are given in both S.I. and U.S. Customary units. The EA seat development effort was carried out at the NASA Langley Research Center and tested on the B-720 aircraft used for the FAA/NASA Controlled Impact Demonstration Test.

## SEAT SELECTION

The commercial transport passenger seat selected by NASA Langley for modification to an energy-absorbing collapsible seat was a triple passenger seat manufactured by the Fairchild Burns Company, Winston Salem, North Carolina.

The seat (trade name Airest 2000*) was deemed typical of the designs now employed by commercial airlines on modern air transports. The seat's basic structure consists of a rectangular shaped frame fashioned from nominal

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4.45-cm (1 3/4-in.) outside diameter aluminum tubes. Four forged aluminum legs, bolted to the frame and stabilized by two aluminum diagonal- and base-rail attach members, support the seat and its occupants. Plastics plus lightweight cushions and covers complete the outer appearance. Weighing about 25 kg (55 lb), the seat possesses excellent strength-versus-weight qualities. Figure 1 illustrates a frontal view of the Airest 2000, while Fig. 2 displays the structural features.

## DESIGN GOAL

The design goal in the development of an energy-absorbing passenger seat for a transport aircraft was to protect the passengers, simulated by three 75-kg (165 lb) anthropomorphic dummies, against both a vertical and longitudinal velocity change of 6.40 m/sec. (21 ft/sec). Each of the three dummies represents a 50th percentile passenger, defined in reference 1. Figures 3 and 4 present graphic data pertaining to human tolerance acceleration limits for vertical and horizontal motion (reference 2).

## SEAT MODIFICATION DESIGN

Several innovative design changes were featured in converting the standard triple passenger seat (Fig. 5) to an EA unit. To limit acceleration the seat was modified (Fig. 6) so that it would rotate forward under high load. To allow seat rotation, split-sleeve-type bearings were affixed to the upper ends of the rear legs and a combination nylon bearing, block-steel yoke unit was installed on the upper ends of the forward legs. All bearings sufficiently encircled the seat frame tubes to allow rotation and yet withstand the impact loads. Conventional aircraft bolts were employed as hingepins to permit pivot rotation of both the forward and rear legs at their lower seat rail attachment. These changes effectively converted the standard seat to a four-bar linkage system. The original flexible membrane seat pan was replaced with a 0.079-mm (1/32-in.) thick aluminum sheet. Both forward and rear legs were inclined parallel to each other at an angle approximately 65° with the horizontal. Two graphite-epoxy, energy-absorbing tubes, installed diagonally between the forward and rear seat legs (Fig. 6), replaced in the original diagonal members to stabilize the seat under normal flight conditions. The tubes progressively crush as axial columns during the aircraft impact. Figure 5 displays a graphic cross section of the unaltered standard seat. Figure 6 depicts the same cross section of the modified seat for comparison. The energy-absorbing, graphite/epoxy tubes, associated tube attachment hardware, and overall seat dimensions are shown. Note that the passenger seat pan height above the aircraft floor level and body posture angle are the same in both standard and modified designs. Figure 7 graphically traces the kinematic stroke of the seat during the energy-absorbing process. The stroke is limited by hardware constraints to a maximum distance of about 16.5 cm (6.5 in.).

## ENERGY-ABSORBING TUBE DESIGN

Various design characteristics were considered when selecting the energy-absorber device. The energy absorber should be lightweight, small, and as simple as possible to be cost effective. It should possess long-term

reliability, require minimum maintenance, and be corrosive/environmental resistant, and unaffected by vibration. Most importantly, the device must decelerate the passengers while not exceeding the load limits of human tolerance.

Graphite epoxy crushable tubes were chosen to meet the requirements for the energy-absorbing process. Since the energy absorption is a function of the materials (fiber and matrix) and ply orientation, the tubes could be readily tailored to absorb the dummies' kinetic energy. A series of developmental tests plus the knowledge gained from a recent study (reference 3) resulted in the selection of 10- and 12-ply graphite-epoxy tubes 21.08 cm (8.30 in.) in length to balance the uneven seat weight distribution caused by lack of symmetry between the seat legs and the occupant seating positions. The tubes were fabricated from the prepreg material of Thornel 300 graphite fibers and Narmco 5208 matrix composed of an MY720 epoxide base. Each ply had a nominal 0.0140-cm (0.0055-in.) thickness and a ply orientation of $\pm 60°$. Data from investigations (refernce 3) indicated changes in energy-absorbing values from 90° to 45° ply orientation; thus, 60° was selected for size and strength considerations. A taper and circular notches (Fig. 8) were machined on one end of the tubes to reduce an initial high load spike without affecting the sustained crushing load.

During the development phase of the composite tubes, static and dynamic tests were conducted to determine the crush load-displacement characteristics and the deceleration-time response of the tube. The static tests were conducted on a 533,786-N (120,000-lb) capacity compression-testing machine. During the static tests, a cap was placed on the tapered end of the tube and a plug was inserted in the flat end to simulate the effect of the cap and plug used in th seat mechanism that holds the tube in place. The crush force-displacement curve for a 6-ply composite tube is shown in Fig. 9. Figures 10 and 11 display the static tests results for the 10- and 12-ply tubes used in the seat. Although the proper initial force level was achieved, the 12-ply tube crushing load was found to increase at a high rate after 4 in. of crush (Fig. 11) because the crushed material filled the remaining volume of the tube. A larger-diameter tube with less plies would have been more desirable but would have required making new end caps.

The dynamic tests on the tube were performed on a drop-tower impact-test machine. A weighted head of approximately 77 kg (170 lb), guided by two rails, was dropped vertically on the tube. Deceleration of the head was measured using accelerometers and was recorded on a strip-chart recorder. A typical deceleration-time curve for a 6-ply-tube dynamic test is displayed in Fig. 12. Head-impact velocity was 4.52 m/sec (14.83 ft/sec), resulting from a drop height of 1.04 m (3.42 ft). Pulse time was about 70 ms. Deceleration ranged between 6 and 12 g. Compacted crushed material, filling the remaining volume of the tube during the tube-crushing energy-absorbing process, accounted for the deceleration g buildup. About 21-cm (6.4-in.) length of tube crushed in absorbing the head's kinetic energy.

# STATIC AND DYNAMIC SEAT TESTS

## Static Seat Test

With the graphite-epoxy tubes in place on the assembled seat, a problem arose during static loading tests conducted to determine maximum stroke distance. A local bending condition at the ends of the graphite-epoxy tubes prevented uniform axial crushing and resulted in tube failure. The problem was solved by the installation of an axial aligning pivot cap and plug attachment at each end of the tube. As the seat stroked downward and forward, the pivot attachment mechanisms caused the tubes to crush uniformly in an axial compressive mode.

The utilization of this mechanism has several possibilities. The energy-absorbing device aligns only in one direction, since the seat had a misalignment problem in only one plane of rotation. A ball joint could be used for multidirection misalignment if necessary. It should provide a useful tool to other designers working with compressively loaded energy absorbers that require the dual characteristics of movable joints and fixed axial alignment conditions. This application is ideal for composite tubes which crush in a brittle mode and are thus difficult to control.

In actual use, the seat is unevenly loaded because of lack of symmetry between the seat legs location and the occupant seating positions. The outboard legs sustain twice the laod of the inboard legs because cf the offset. However, this effect was nullified during static seat test by locating the hydraulic ram symmetrically between the seat legs. For this symmetrically loaded seat, both composite tubes were 6 ply. Four static tests were performed to check the operation of the seat mechanism. The applied vertical load (hydraulic ram), and the vertical (Z) and horizontal (X) floor reaction forces for a typical test are shown in Fig. 13.

## Dynamic Seat Tests

The assembled seat, with installed 10- and 12-ply EA tubes, was dynamically tested at the Langley Research Center's Dynamic Impact Test Facility. A series of dynamic drop tests were conducted to simulate the vertical and forward expected shock pulse characteristics. The drop tests were accomplished by mounting the seat at a 45° tilt angle to the horizontal flat surface of a steel carriage. The carriage structure basically consisted of two horizontally positioned, built-up beam units, connected by steel plate members. The carriage, with the 45° tilted seat containing the three anthropomorphic dummies, was then raised and dropped vertically. Impact pulse was controlled by permitting the falling carriage to strike and deform a series of steel bars at ground level. The dummies were restrained by lap belts and were positioned leaning forward with their head between their legs in a crash preparation body posture. Data acquisition consisted of accelerometers, load cells extensiometers, and high-speed motion picture cameras. This method of dynamic impact testing was based on knowledge and techniques established by many previous experiments performed at the Langley Research Center (see reference 4). Figure 14 illustrates an actual stroked

seat which resulted from these shock tests. About 12.7 cm (5 in.) of each composite tube crushed from the 4.27-m (14-ft) drop height, in absorbing the dummy passenger kinetic energy. Carriage input pulse plotted with the resulting pulse on the seat pan is shown in Fig. 15. Acceleration levels remained within the range of human tolerance levels (see Fig. 1 and 2). Data analysis of the seat from the Boeing 720 crash had not been completed at the time this paper was prepared.

## CONCLUSIONS

This investigation applies the concept of an energy-absorbing, axial, tube-crushing unit to commerical aviation passenger transport seats. The investigative effort was limited by the primary schedule of the Controlled Impact Demonstration Project which prevented optimizing the energy absorbers. For optimum seat performance, further development of the energy absorbers is recommended.

Such parameters as belt restraints, varying passenger seat weight loads and their distribution, seat rebound, and economic aspects must be examined.

Preliminary results from the work conducted so far are encouraging. The desired objective of demonstrating the concept/feasibility of converting a standard commercial passenger seat to a axial, tube-crushing, energy-absorbing unit as an additional crash safety feature has been attained.

## REFERENCES

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3. Farley, Gary L.: Energy Absorption of Composite Materials. NASA TM-84638, March 1983. Also, Journal of Composite Materials, vol. 17, May 1983, pp. 267-279.

4. Alfaro-Bou, Emilio; Williams, M.S.; and Fasanella, E. L.: Determination of Crash Test Pulses and Their Application to Aircraft Seat Analysis: SAE Paper 81061, Business Aircraft eeting and Exposition (Wichita, Kansas), April 7-10, 1981.

Figure 1. – Airest 2000 Triple Seat

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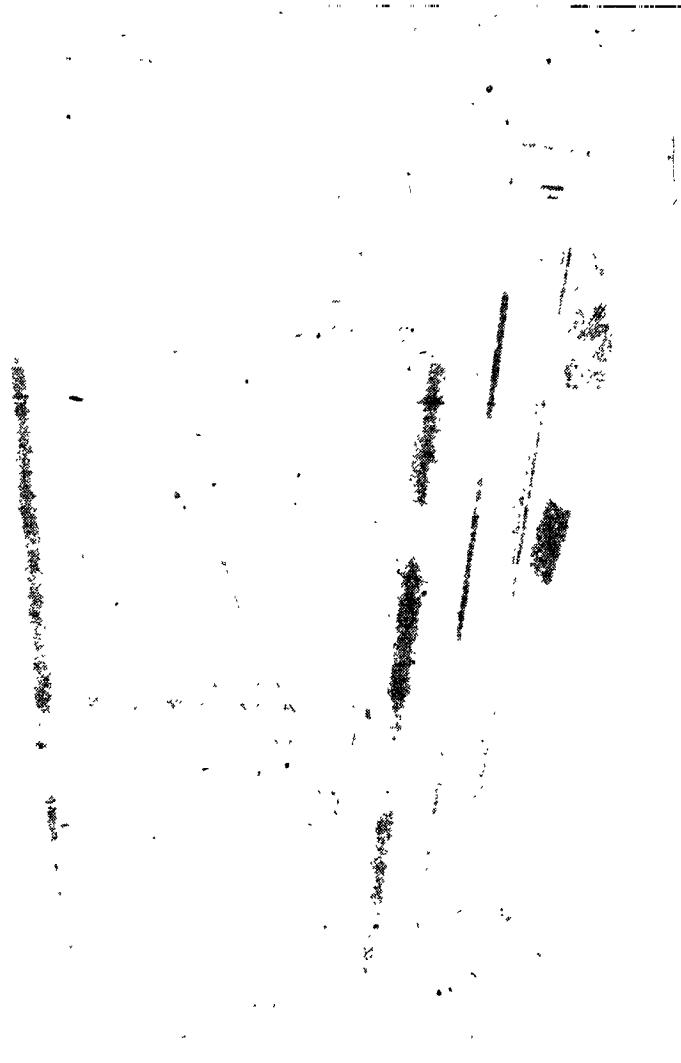
Figure 2. - Airest Seat - Structure View
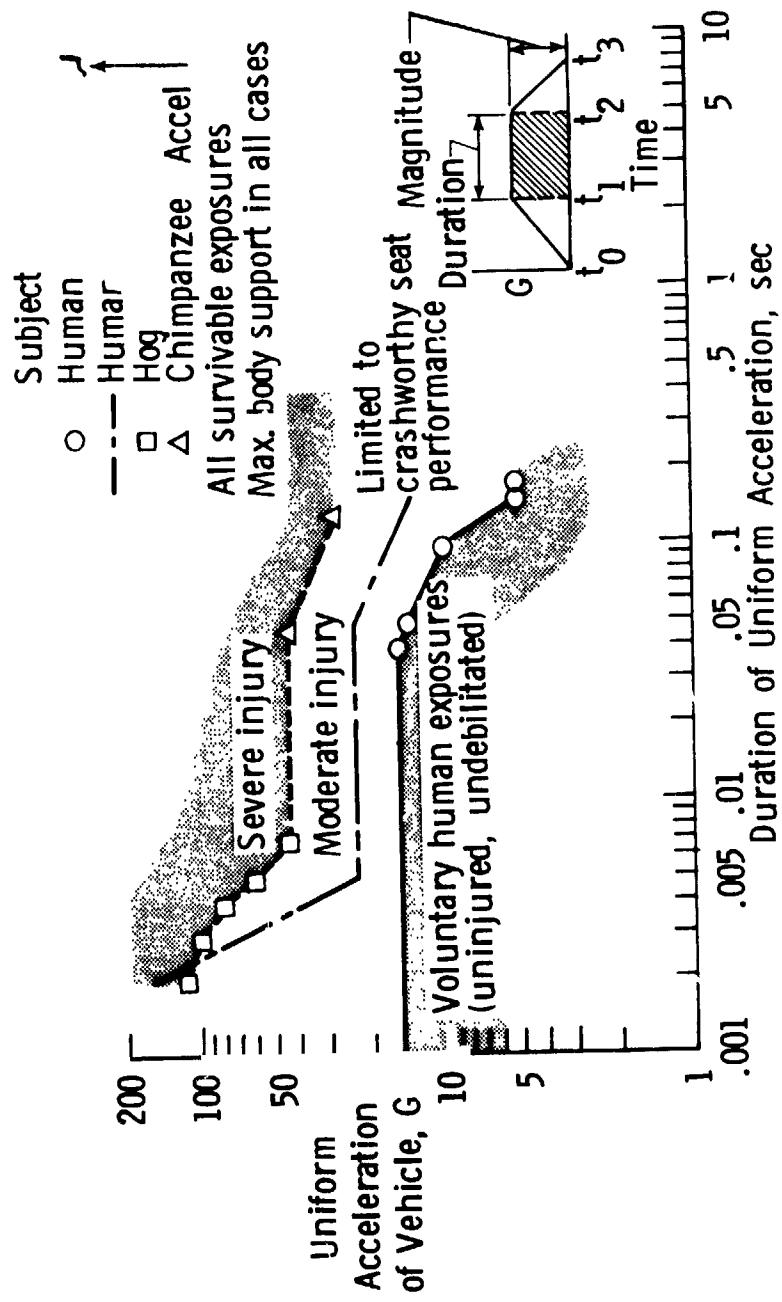
Figure 3. - Duration and Magnitude of Headward Acceleration Endured by Various Subjects. (From Reference 2)
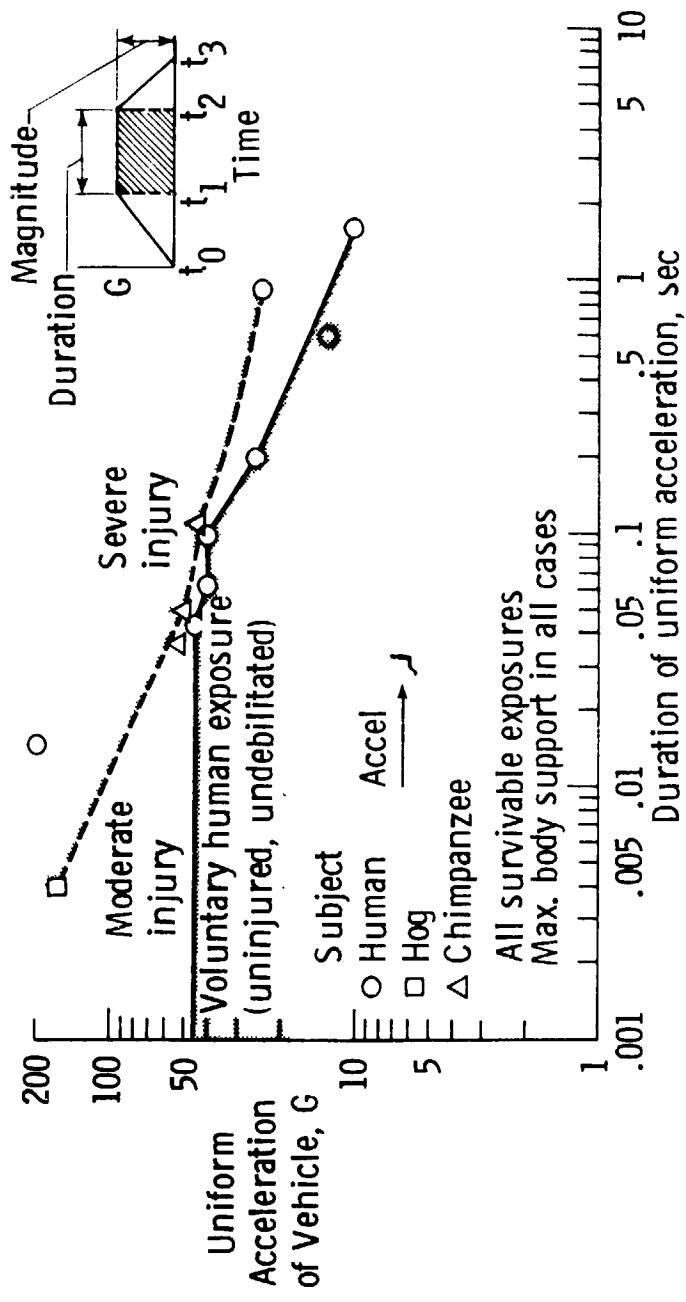
Figure 4. – Duration and Magnitude of Spineward Acceleration Endured by Various Subjects. (From Reference 2)
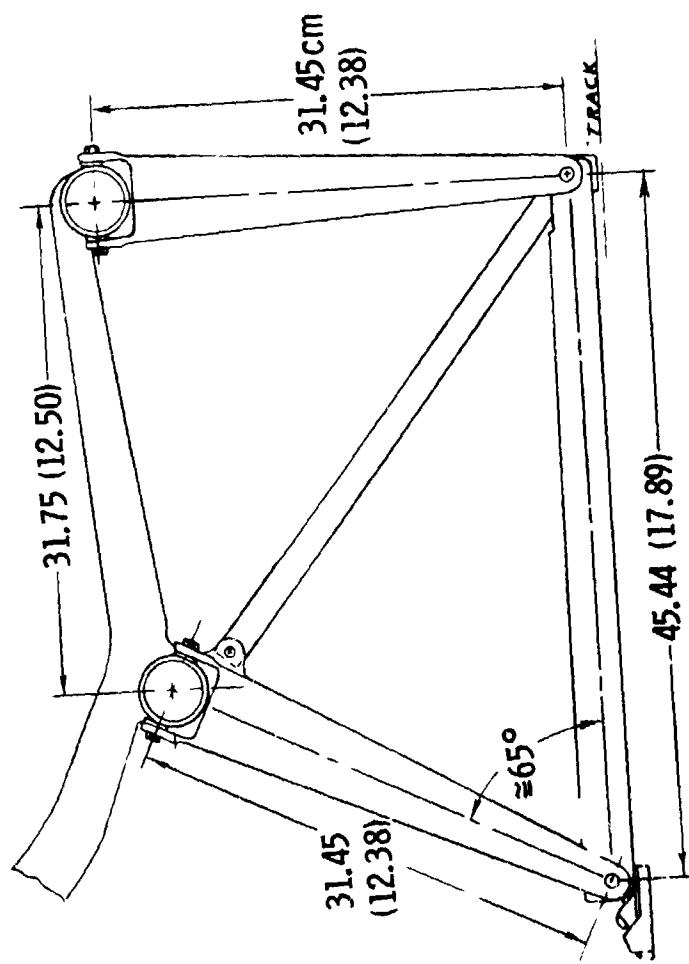
Figure 5. - Airest Seat Cross Section
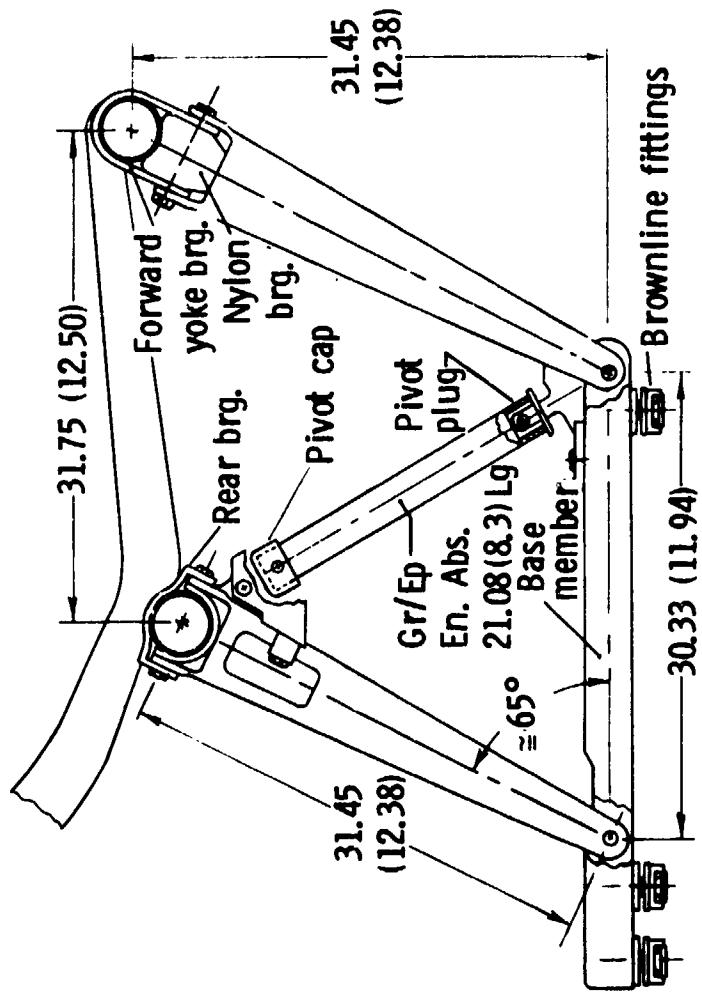
Figure 6. – Modified Seat Cross Section

0cm(in.)
2.54cm(1.0in.)
15.24cm
(6.0in.)
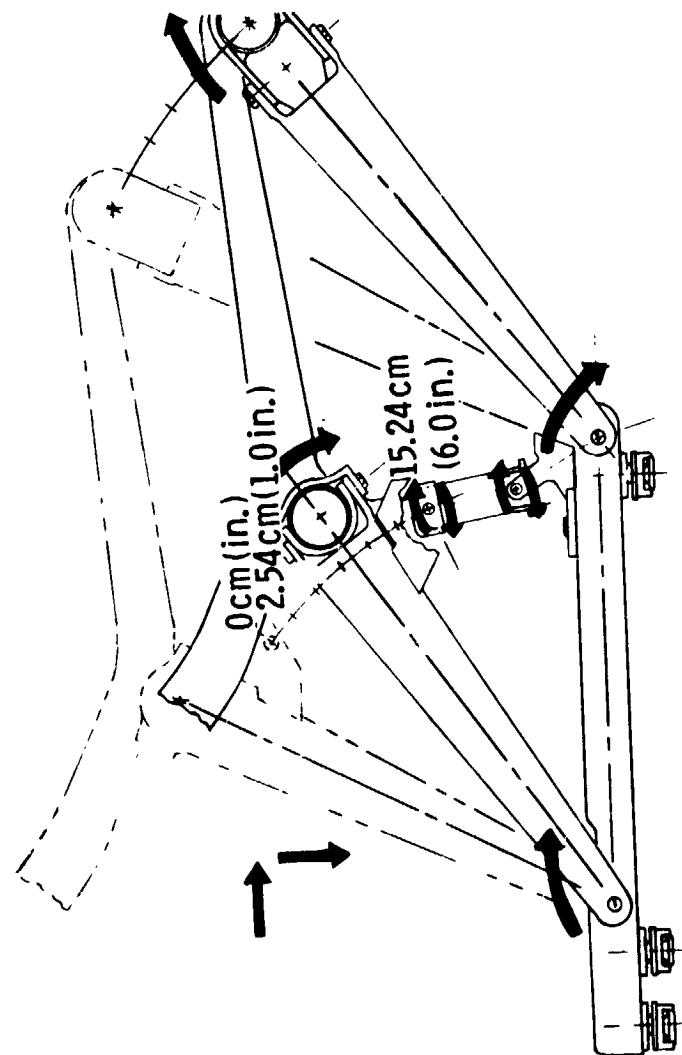
Figure 7. – Seat Kinematic Stroke
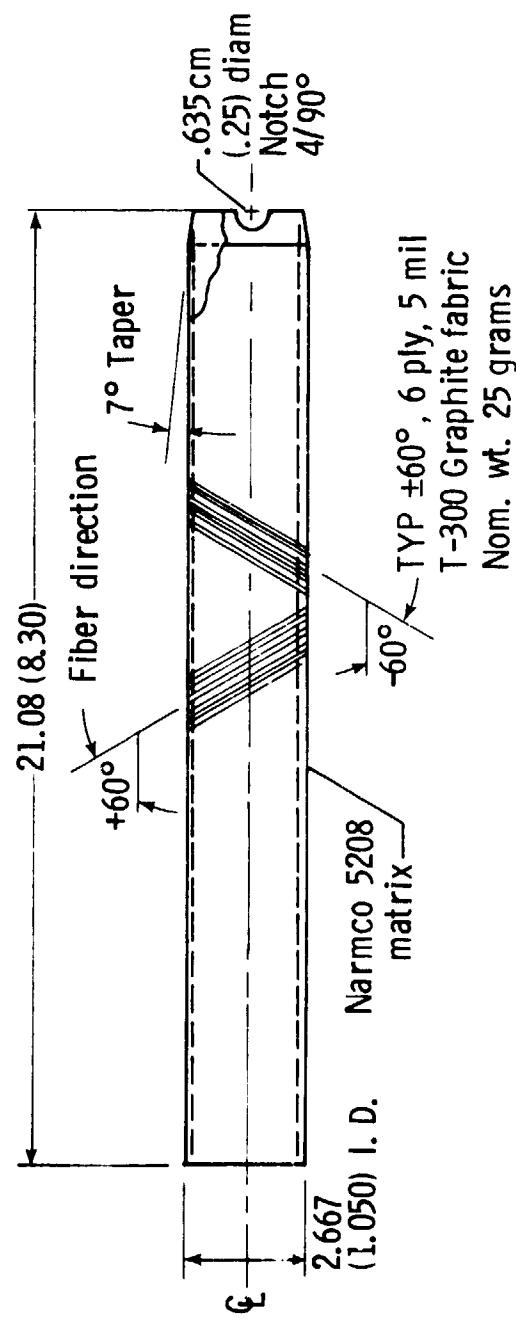
Figure 8. – Typical Energy Absorbing Tube
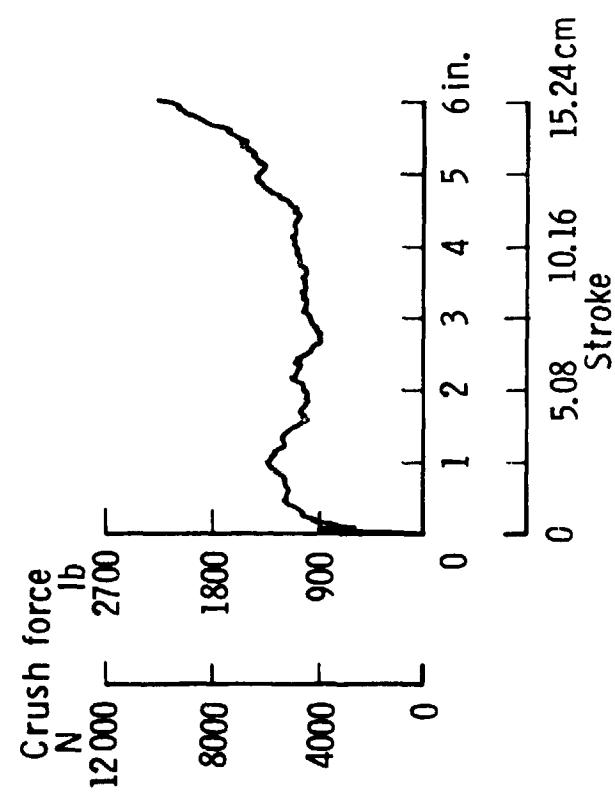
Figure 9. – Static Crush Force VS Displacement, 6 Ply Tube
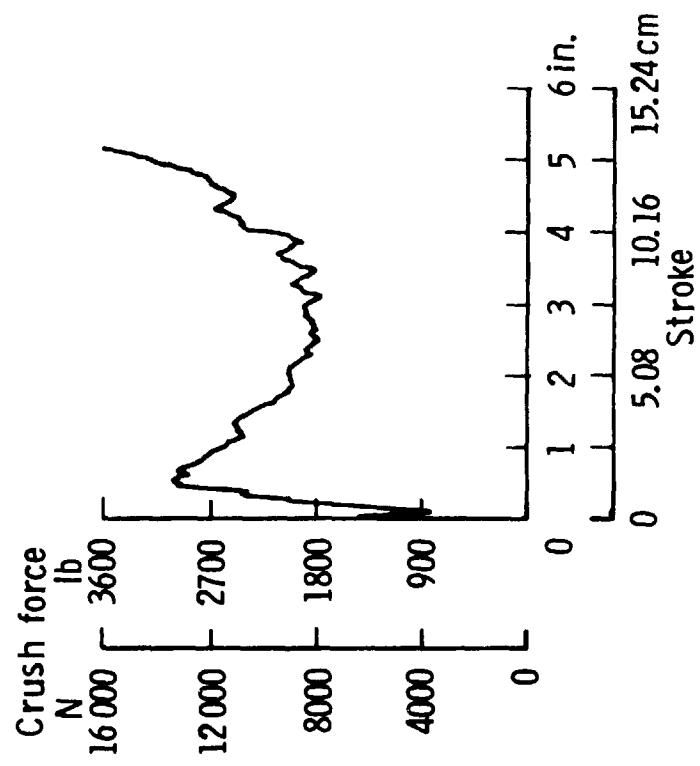
Figure 10. – Static Crush Force VS Displacement, Seat 10 Ply Tube
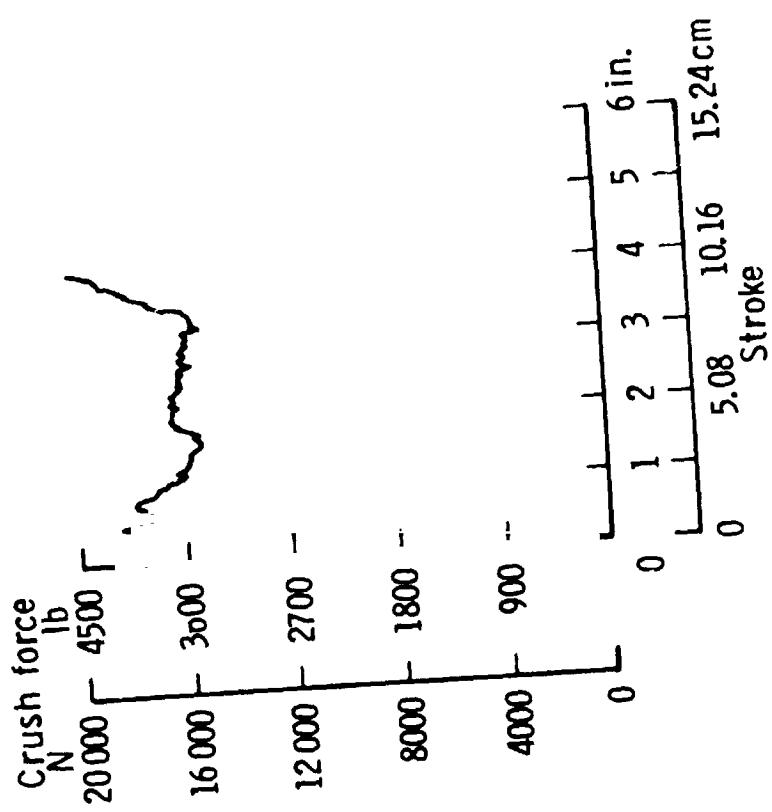
Figure 11. - Static Crush Force VS Displacement, Seat 12 Ply Tube
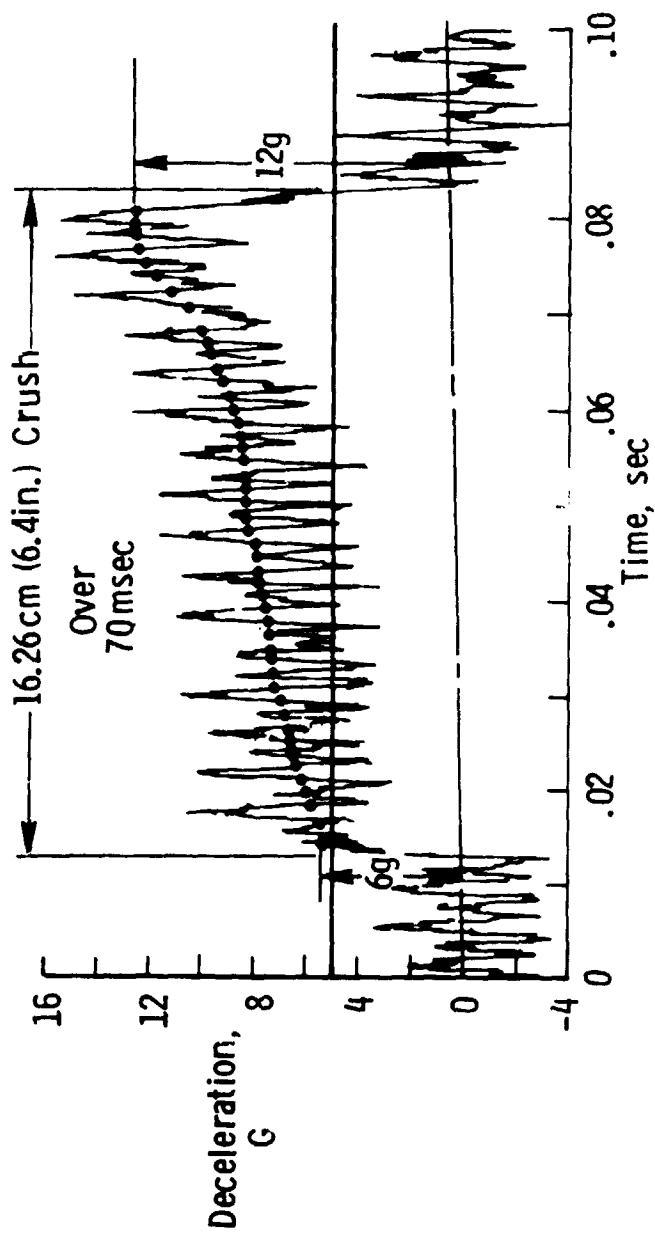
Figure 12. – Typical EA Deceleration Time Curve, 6 Ply Tube

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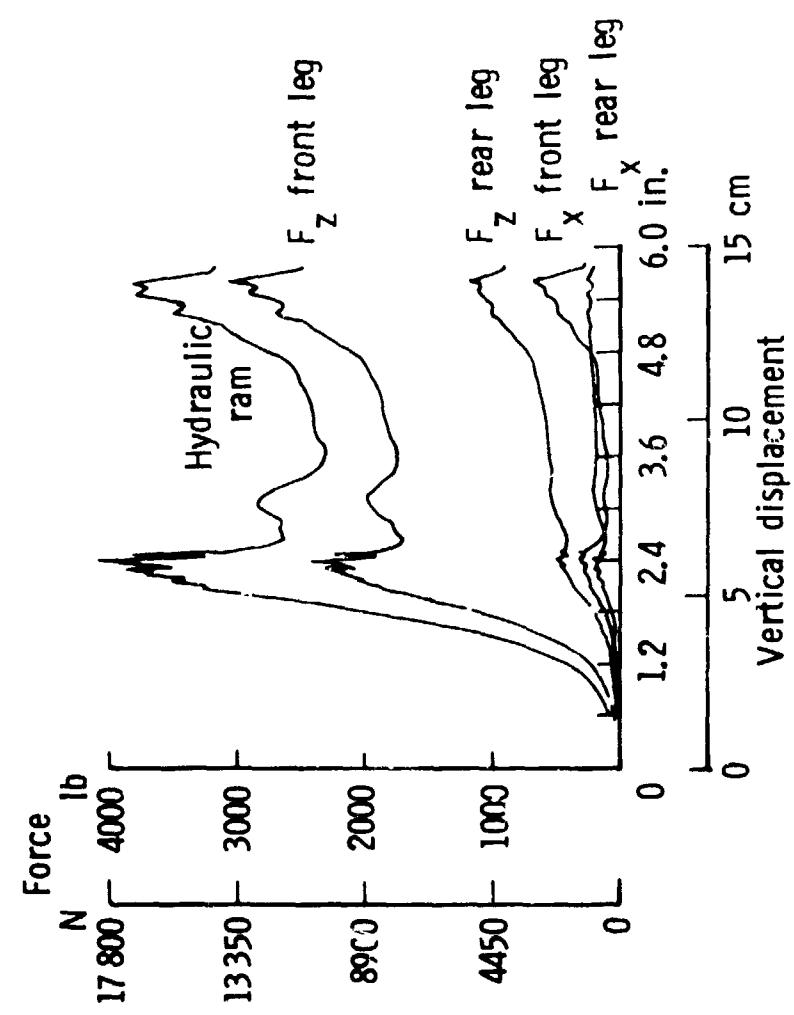
Figure 13. – Static Seat Test, Force VS Vertical Displacement

Figure 14. – Dynamic Impact Test – Stroked Seat

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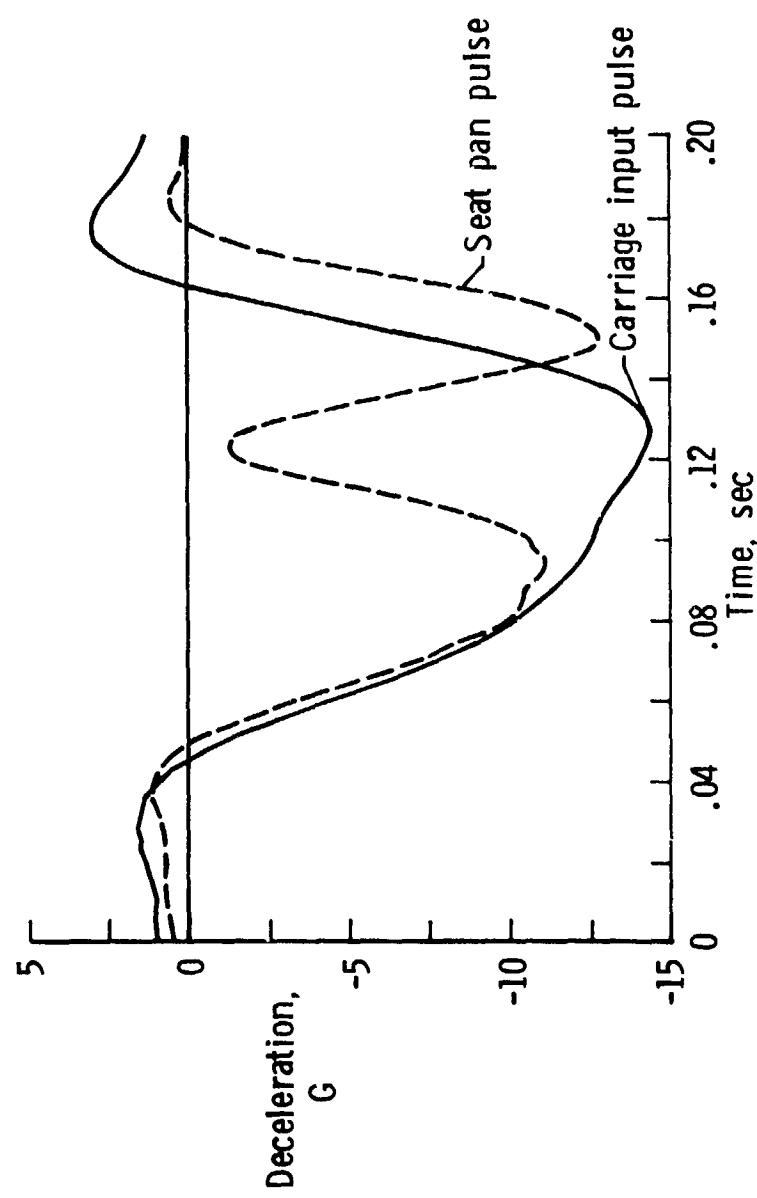
Figure 15. - Dynamic Impact Seat Test, Carriage and Seat Pan Pulse Levels