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# An Experimental Abdominal Pressure Measurement Device for Child ATDs

Richard L. DeWeese
Civil Aeromedical Institute
Federal Aviation Administration
Oklahoma City, Oklahoma 73125

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16. Abstract

An experimental device to measure the abdominal pressure in child-size Anthropomorphic Test Dummies (ATDs) during dynamic tests was developed. A description is provided of the two ATDs in which the device was installed, the CRABI six-month-old and the CAMIX two-year-old size ATD. The test device's construction and installation in the ATDs is described. The instrumented ATDs were used to evaluate the performance of child restraint devices when installed in a typical transport aircraft passenger seat. The restraints evaluated were booster seats, normal lap belts, and a lap-held child restraint called the "belly belt." The test severity was 16 Gpk. with an impact velocity of 44 ft/sec. Descriptions of the test setups are provided. Analyses are presented of the pressure measurements acquired from the tests and the ATD/restraint system interactions that produced them.

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# AN EXPERIMENTAL ABDOMINAL PRESSURE MEASUREMENT DEVICE FOR CHILD ATDS

## INTRODUCTION

This report describes an experimental instrumentation system to measure abdominal pressure in child anthropomorphic test dummies (ATDs). The system was developed at the Federal Aviation Administration (FAA) Civil Aeromedical Institute (CAMI) Biodynamics Research Section. This experimental device was part of a project to evaluate the performance of Child Restraint Devices (CRDs) in airplane seats (1). Dynamic impact tests were performed with the abdominal pressure measurement system installed in two types of child ATDs. The first was a two-year-old size ATD developed at CAMI, and the second was a six-month-old size ATD developed by the automotive industry. A description of the ATDs, abdominal instrumentation, and the responses acquired from dynamic impact tests are presented in this report.

Experimental systems to measure abdominal pressure and intrusion in child size ATDs have been reported previously (2,3). These research projects used a three-year-old size child dummy. The test protocols were designed to represent the restraint of a child in an automobile. This project focused on CRDs in transport airplane passenger seats.

## CHILD ATDS

A two-year-old size child dummy, identified as CAMIX, was designed and constructed by Richard Chandler and Joseph Young at CAMI in 1989. Construction of this special dummy was necessary since, at the time, there was no commercially available ATD of this size. A photograph of the ATD is shown in Figure 1. The two-year-old size was chosen because that age is specified in the Federal Aviation Regulations (FAR) as the oldest age for a child allowed to be held on the lap of an adult during take off and landing (4). The CAMIX ATD's anthropometry was designed to represent a seated, 50th percentile, two-year-old child. Tables 1 and 2 present the body segments, dimensions, and weights for this size of child. These measurements were based on U.S. child anthropometry surveys conducted by the University of Michigan's Highway Safety Research Institute (5).

The CAMIX ATD was constructed using commonly available materials. A spine was constructed with parallel 0.4-inch diameter Kevlar cables sandwiched between a series of wood blocks to provide stiffness. The pelvis was a cast metal structure shaped and dimensioned to represent a two year-old ATD's pelvis. The chest, head, and abdomen were shaped from Ensolite foam. Skin over the torso was made from leather, covering the chest, abdomen, back, and thighs. The limb segments were fabricated with 0.4 inch diameter Kevlar cables inserted through hollow wood columns. Soft foam was wrapped over the limb segments and covered with elastic nylon material to form the skin. The dummy's limbs were articulated within the normal range of motion, but no provisions for joint stiffness were included.

A hemispherical cavity in the abdomen of the CAMIX ATD was included to contain abdominal instrumentation. The walls of the abdominal cavity were made with semi-rigid Ethafoam. Other than provisions for the abdominal device, no other instrumentation was available with the CAMIX ATD. The weight of the CAMIX ATD was 27 lb., including the abdominal pressure sensing system.

The second ATD used to evaluate abdominal pressure was the six-month-old size Child Restraint Air Bag Interaction (CRABI) dummy. This ATD was developed recently by the automotive industry (6). The specific purpose of the ATD was to evaluate the effects of automobile air bags on a small child restrained in a CRD during a crash. It included articulated limbs, a Hybrid III type neck, and a variety of instrumentation locations. The CRABI ATD weighed 17 lb. without instrumentation.

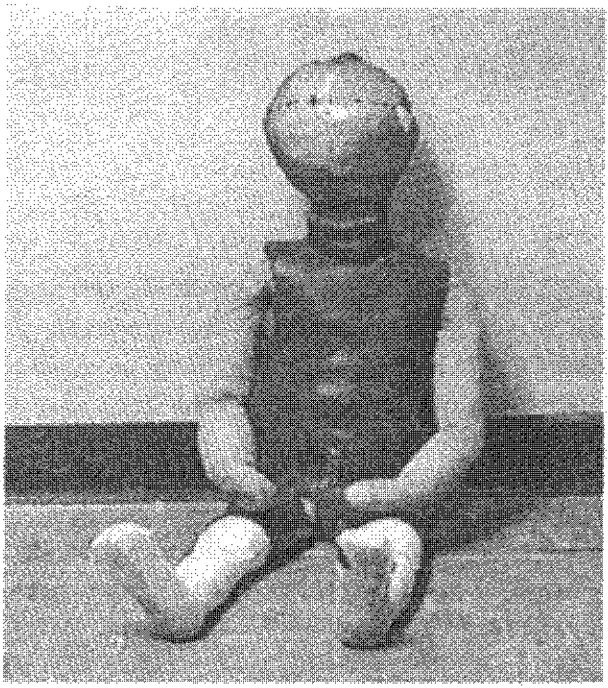

Figure 1.

Figure 2.

## ABDOMINAL PRESSURE INSTRUMENTATION

The experimental system for abdominal pressure measurement was designed specifically for installation in the CAMIX ATD. The system consisted of a 500 ml medical intravenous fluid bag (Baxter Viaflex container) filled with 600 ml of water. This volume of water filled the bag tightly and left no air volume. A Statham model PG822 250 psi pressure transducer was coupled to the outlet tube. Direct coupling of the pressure sensor to the incompressible fluid in the bag provided an indication of the instantaneous pressure in the volume of the abdomen occupied by the bag. The bag was installed vertically in the abdominal cavity and was supported on all sides by the Ethafoam wall lining of the cavity, as shown in Figure 2. The abdominal cavity was filled completely by the bag.

Shown in Figures 3 and 4, this same instrumentation was adapted for the CRABI ATD. The volume of water in the fluid bag was reduced to 300 ml without introducing any air into the bag. The bag and pressure sensor assembly was inserted horizontally in the hollow abdominal cavity of the CRABI ATD. One side of the bag was supported by the ATD's rigid lumbar spine, and the other was supported by the outer rubber skin. The ends of the bag were essentially unsupported. Installation of the abdominal pressure measurement system added 1.5 lb. of weight, which was an 8.6% increase in total weight.

## TEST METHOD

The instrumented ATDs were used in a series of dynamic impact sled tests conducted by CAMI to evaluate the performance of CRDs installed in transport airplane passenger seats. Figures 5 and 6 are photographs of the test sled setups. All tests were forward-facing horizontal tests with no yaw angle. The passenger seats were typical economy class triples. Test conditions for all tests were those defined in Federal Aviation Regulation Part 25.562 (7) for certification of transport category airplane seats. This severity requires a 16 Gpk. with an impact velocity of 44 ft/sec. A typical sled deceleration pulse from this series is shown in Figure 7.

There was no attempt to establish the biofidelity of the abdominal instrumentation in the two ATDs used with this device. No injury criteria exist for

## Anthropometric Characteristics of a 50th Percentile Two-Year-Old Child

| Segment | Percent of Total Body Weight | Segment Weight (lb.) |
|---|---|---|
| Head & Neck | 12.9 | 3.51 |
| Upper Torso | 31.8 | 8.65 |
| Lower Torso | 13.3 | 3.62 |
| Upper Arms | 2 X 7.1 = 14.2 | 2 X 1.93 = 3.86 |
| Forearms | 2 X 4.3 = 8.6 | 2 X 1.17 = 2.34 |
| Hands | 2 X 1 = 2.0 | 2 X 0.27 = 0.54 |
| Thighs | 2 X 4.7 = 9.4 | 2 X 1.28 = 2.56 |
| Lower Legs | 2 X 2.7 = 5.4 | 2 X 0.73 = 1.46 |
| Feet | 2 X 1.2 = 2.4 | 2 x 0.33 = 0.66 |
| TOTALS | 100% | 27.2 lb. |

Table 1.

## Body Segment Dimensions for a 50th Percentile Two-Year-Old Child

| Body Segment | Dimension (inches) | Body Segment | Dimension (inches) |
|---|---|---|---|
| Stature | 34 | Chest Breadth | 6.6 |
| Sitting Height | 20.3 | Chest Depth | 4.6 |
| Shoulder Height, Seated | 12.6 | Waist Breadth | 5.9 |
| Shoulder-Elbow Length | 6.8 | Waist Depth, Seated | 5.9 |
| Elbow-Hand Length | 9 | Hip Breadth | 7.3 |
| Buttock-Knee Length | 9.8 | Head Circumference | 19.2 |
| Knee-Foot Length | 9.6 | Neck Circumference | 9.2 |
| Crotch-Foot Length | 13.4 | Chest Circumference | 19.2 |
| Shoulder Breadth | 9.2 | Waist Circumference | 18.1 |

Table 2.

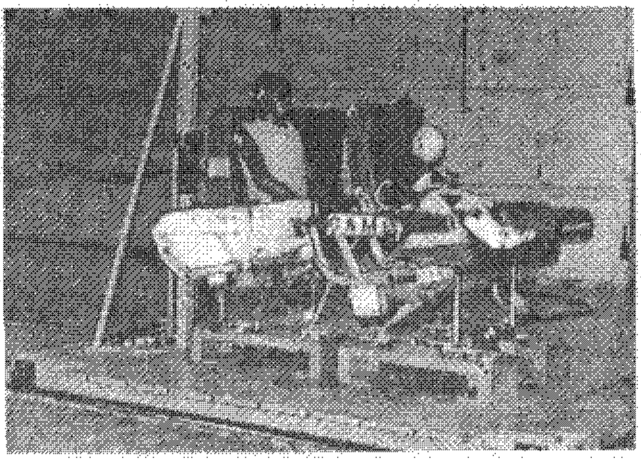

Figure 5.

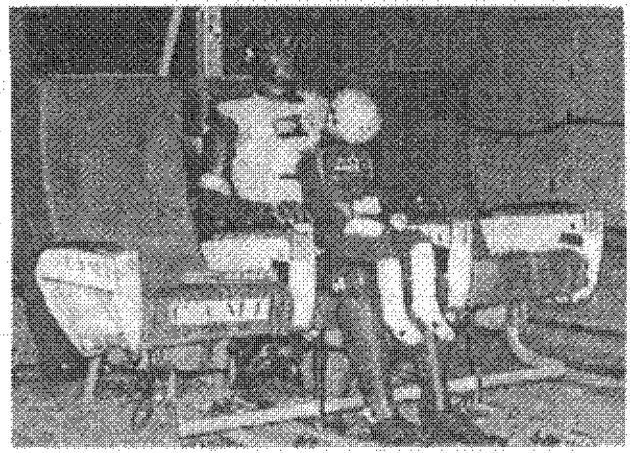

Figure 6.

the tray table. The second was a single row with locked out seat back breakover, where the seat back hinge mechanism was rigidly locked. The third was a double row that placed the CRD in a seat with normal seat back breakover, and placed a Hybrid II ATD directly behind in the aft row. The purpose of the aft row occupant was to assess the effect of its flail on the occupant of the CRD.

The belly belt tests were conducted with a child ATD seated in the lap of an adult ATD. For one test with the CAMIX ATD, the adult's upper torso was restrained from flailing forward. This was done to assess the abdominal loads generated, independent of adult occupant flail. For the second test with the CAMIX ATD, a seat with locked out breakover was placed in front of the occupants. In the third test with the CAMIX ATD, a Hybrid II ATD was placed directly behind the occupants to assess the effect of its flail on them. For the test with the CRABI ATD, a seat with normal seat back breakover was placed in front of the occupants.

The normal aircraft lap belts were tested in a seat with breakover locked out, as well as in a double-row test configuration. The double-row test placed the CAMIX ATD in a seat with normal seat back breakover, and placed a Hybrid II ATD directly behind in the aft row.

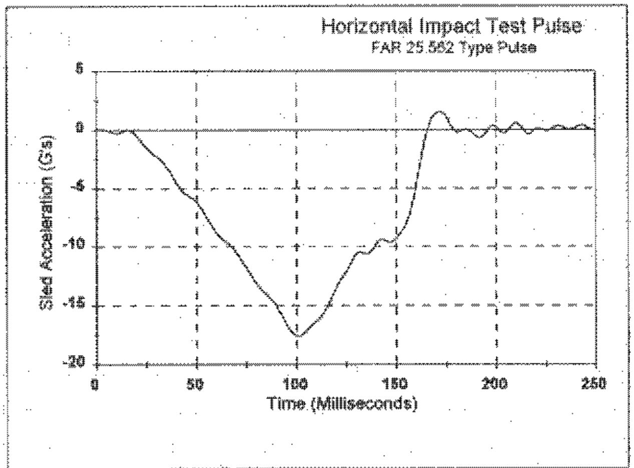


Figure 7.

## RESULTS

Figure 8 presents the abdominal pressure responses from the tests with booster seats. The single-row tests produced very similar results regardless of the make of the CRD or the seat back breakover configuration. The pressures produced appeared to be caused by the inertial load of the ATD acting on the CRD shield. The double-row test showed very similar response to the single row tests up to the point of impact by the aft-row occupant. The impact of the aft-row occupant onto the seat back coincided with the largest pressure spike, 58.9 psig, that was recorded.

| Test Number | ATD | Restraint System | Special Conditions |
|---|---|---|---|
| A93035 | CAMIX | Booster Seat | Seat back beakover locked out |
| A93036 | CAMIX | Booster Seat | Normal seat back breakover |
| A93037 | CAMIX | Booster Seat | Seat back breakover locked out |
| A93038 | CAMIX | Lap Belt Only | Seat back breakover locked out |
| A93039 | CAMIX | Belly Belt | Adult upper torso restrained |
| A93040 | CRABI | Belly Belt | Adult and lap-held child ATDs in aft row seat |
| A93048 | CAMIX | Booster Seat | Child ATD in forward row, adult ATD in aft row |
| A93050 | CAMIX | Belly Belt | Child/adult ATD in aft row of double row test |
| A94164 | CAMIX | Lap Belt Only | Child ATD in forward row, adult ATD in aft row |
| A94165 | CAMIX | Belly Belt | Child/adult ATD in forward row, adult ATD in aft row |

**Table 3.**

Note in Figure 8 the damped oscillation response after the peak pressure pulse from test A93048. The high frequency transient characteristic of this data may be an artifact of the instrumentation. There were two potential causes for this atypical data. Either mechanical excitation of the pressure transducer within the ATD, or fluid pressure oscillations due to the high pressure load may have produced the phenomenon. However, this pressure response did coincide with the period during which the aft row occupant was bearing on the forward row seat back. While the value of the pressure measurement may have been influenced by these instrumentation anomalies, it is clear that there was a very high energy pulse delivered to the abdomen in a short period of time.

Figure 9 presents the abdominal pressure responses from the tests with lap belt restraint systems using the CAMIX ATD. The pressure response in test A93038, which used normal aircraft lap belts, was the lowest abdominal pressure recorded. An examination of the high-speed films from this test revealed the lap belts remained over the pelvis of the dummy and did not load the abdomen directly. The small abdominal pressure peaks that were recorded during this test were coincident with the child ATD's torso impacting its own legs and the seat structure. In test A94164, which placed an adult occupant directly behind the lap belt restrained CAMIX ATD, the pressure response was similar to test A93038 until the adult impacted the seat back. This impact coincided with a 36.7 psig pressure spike and damped oscillatory response similar in nature to that seen in test A93048 with the booster seat. Although the response is of lower magnitude, the same comments about potential instrumentation anomalies apply to these results.

Figure 10 presents the abdominal pressure responses from the tests with the CAMIX ATD restrained by the belly belt in the lap of an adult ATD. In the first belly belt test, A93039, the CAMIX ATD was seated on an adult ATD's lap whose upper torso was restrained from flailing. Pressure response from this test was similar to the booster seat tests up to the point when the child ATD started to rotate forward. This is not surprising since the load path is similar, although more concentrated with the belly belt. When the child ATD doubled over, pressure increased by 50%, then dropped off as the ATD rebounded.

In test A93050, the CAMIX ATD was restrained by a belly belt in the lap of an adult ATD that was, in turn, restrained by a lap belt. During this test, the pressure response increased as the adult ATD rotated forward and pressed the child ATD against the upright forward row seat back, then subsided as the adult rebounded. The maximum pressure magnitude during this test was in the same range as test A93039, but had a longer duration peak.

In test A94165, the CAMIX ATD was restrained by a belly belt in the lap of an adult ATD seated in the front row of a double row test. An adult ATD was seated directly behind the occupants of the front seat to assess the effect of its flail on them. Without

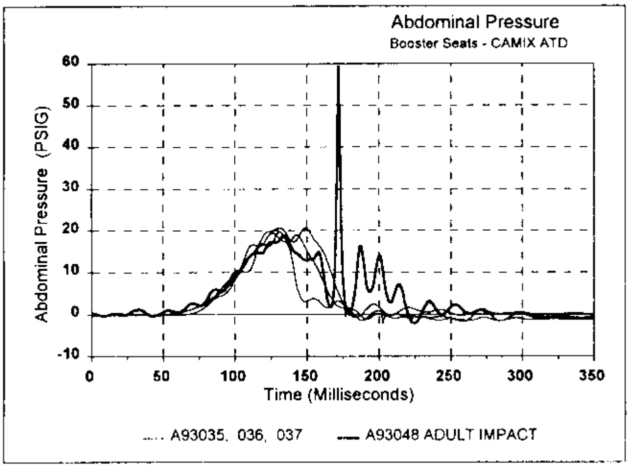


**Figure 8.**

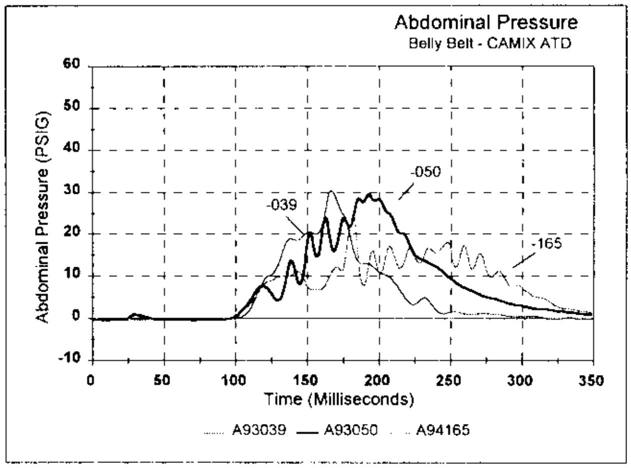


**Figure 10.**

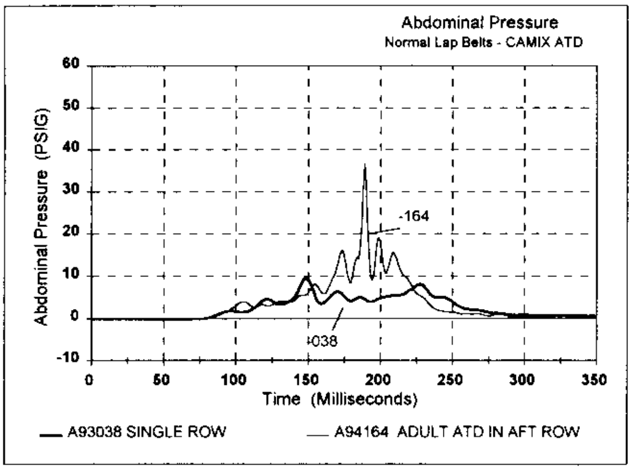


**Figure 9.**

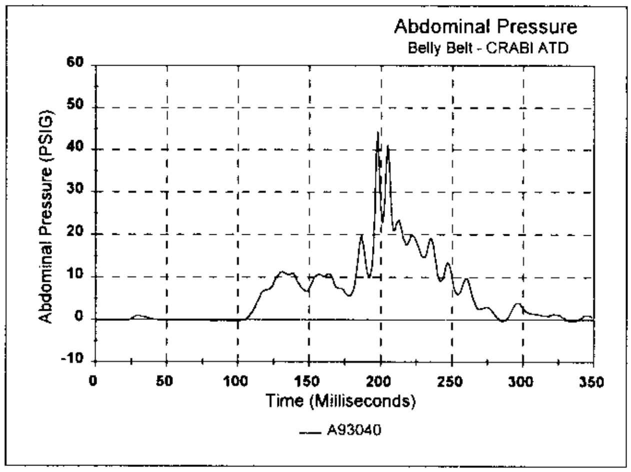


**Figure 11.**

a front seat to stop the child and adult, they flailed forward, with the adult ATD folding over and around the child ATD. The child ATD moved forward on the adult's lap and flailed forward and downward with its head nearly reaching floor level. The abdominal pressure response was somewhat lower in magnitude, but longer in duration than seen in test A93050. The response may be less because the child ATD was sandwiched between the adult's upper torso and legs, rather than being pressed against the rigid seat back. Any effect the impact of the aft row occupant might have had on the pressure response of the child ATD was not clearly evident. Since the kinematics of the two adult ATDs were similar, the sudden rise seen in the pressure response is coincident with both the folding over of the front row adult occupant and the impact of the aft row occupant.

Figure 11 presents the abdominal pressure response for the CRABI ATD restrained by the belly belt in the lap of an adult ATD. The initial 10 psig pressure plateau is due to the inertial load of the ATD being reacted by the belt. The large pressure spike occurs when the child ATD is entrapped between the adult ATD's torso and the forward row seat back. The forward row seat back, which was not locked out, rotated forward early in the test. This allowed the aft row occupants more time to gather momentum before striking it. The impact of the adult ATD onto the back of the child ATD produced a large double pressure spike, followed by a damped oscillating response. Although of lower magnitude, this response was similar to that seen in booster seat test A93048, and the same comments about potential instrumentation anomalies apply to these results.

It was generally noted that sharp rises in abdominal pressure resulted when external forces or ATD kinematics acted to cause rapid compressive loading of the abdominal cavity.

## CONCLUSIONS

The experimental pressure system described in this report provided a quantitative method to measure the restraint loads imposed on the abdomen of the CAMIX and CRABI ATD. Although no injury criterion is currently available to quantify the potential for injury based on the pressure response, the method may be used as a comparative method to evaluate abdominal loading by restraint systems. The additional quantification of an injury potential may not be necessary for this device to be useful. Aircraft seat restraint systems that bear on the abdomen are not allowed by current standards (7). Any restraint system that significantly loads the abdominal region should, therefore, be discouraged, or the external forces causing the abdominal load should be attenuated.

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