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Vertical Impact Tests of a Proposed B-52 Ejection Seat Cushion

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Interim Report for July 2001 to September 2001

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Air Force Research Laboratory
711th Human Performance Wing
Human Effectiveness Directorate
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14. ABSTRACT

A series of vertical impact tests were conducted to compare the impact response of a proposed seat cushion to the response of the existing B-52 ejection seat cushion and a baseline no-cushion configuration. The vertical impact tests were conducted at a magnitude of 10 G using the AFRL/RHPA Vertical Deceleration Tower (VDT), and using a small and large instrumented manikin weighing approximately 103 lb and 217 lb respectively. Five impact tests were conducted per test configuration with each manikin. Instrumentation was used to measure manikin head and chest accelerations, seat pan and seat cushion accelerations, and seat pan and restraint system loads. The impact safety of the proposed cushion was determined by comparing peak seat cushion accelerations and peak seat pan loads. Any differences that were found in the peak loads and accelerations were related to a change in the probability of spinal injury, which was determined using the Dynamic Response Index. Evaluation of the data indicates that the proposed seat cushion slightly improved the response of the large manikin weighing 217 lb, and significantly improved the response of the small manikin weighing 103 lb. The small manikin's lumbar loads were reduced by approximately 20%. The risk of spinal injury for the small manikin was reduced by approximately 65% for an 18 G input simulating the B-52 catapult.

15. SUBJECT TERMS

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PREFACE

An experimental effort was conducted to evaluate the impact safety of a proposed seat cushion for the B-52 ejection seat. A series of vertical impacts were conducted to compare the impact response of the proposed seat cushion to the existing B-52 ejection seat cushion and a baseline no-cushion test configuration. The vertical impacts were conducted at a magnitude of 10 G using the AFRL/RHPA Vertical Deceleration Tower (VDT), and using a small and a large instrumented manikin. The small manikin weighed approximately 103 lb and the large manikin weighed approximately 217 lb. Three impact tests were conducted per test configuration with each manikin. Instrumentation was used to measure manikin head and chest accelerations, seat pan and seat cushion accelerations, and seat pan and restraint system loads. The impact safety of the proposed cushion was determined by comparing peak seat cushion accelerations and peak seat pan loads. Any differences that were found in the peak loads and accelerations were related to a change in the probability of spinal injury, which was determined using the Dynamic Response Index.

The vertical impact tests described in this report were accomplished by the Biodynamics and Acceleration Branch, Biodynamics and Protection Division, Human Effectiveness Directorate of the Air Force Research Laboratory (AFRL/RHPA) at Wright-Patterson OH. Mr. Chris E. Perry was the principle investigator and project manager. The tests were conducted at the request of Major Chris Rounds at the 93rd BS at Barksdale AFB, AL. Test Facility and engineering support were provided by Veridian under contract F41624-97-D-6004.

This report is dedicated to the memory of Mr. Walter Scherer, whose efforts ensured the successful completion of this program.

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1.0 INTRODUCTION

The level of aircrew seat comfort is very important for acceptable operational effectiveness in today's high performance aircraft (both fighters and tactical bombers). This is particularly true as some missions may have the aircrew in their seats for several hours. A recent effort was initiated to improve the current ejection seat cushion for the B-52 aircraft in order to provide a more comfortable cushion for long duration flights. However, even though long-term sitting comfort may be enhanced by a new cushion, it must be determined whether the new cushion will influence the risk for vertebral fracture during ejection. Seat cushions may actually amplify the acceleration transmitted to the torso of the aircrew member if they are not designed properly. This amplification is due to the cushion delaying the onset of acceleration of the occupant or to the cushion absorbing the dynamic energy of the impact and then releasing it during recoil of the cushion material. The advantages of improved sitting comfort afforded by a specific seat cushion in ejection-seat-equipped aircraft, must be balanced by the risk of spinal injury during ejection. A request was issued by the 93rd BS at Barksdale AFB through the 311th HSW/YACSS at Brooks AFB to evaluate the proposed B-52 seat cushion upgrade in terms of increased spinal injury potential.

2.0 BACKGROUND

Long-term sitting comfort can be affected and improved by the alignment of the pelvis and spinal column [3,4,7,8,14]. It has been speculated that a combination of body segment alignment and cushion material selection can improve the occupant's comfort when seated for an extended period of time. Medical research for patients with spinal cord injuries has contributed significant improvements to long-duration sitting comfort. The consequences of less-than-optimum seating comfort have severe medical implication for wheelchair-bound patients. As a result, substantial efforts have been made to produce cushions that will limit peak pressures at specific contact points on the lower body (ischial tuberosities on lower pelvis). However, the application of this technology to improve comfort in the ejection seat must not compromise the risk of spinal injury to the aircrew during ejection.

In 1985, a series of vertical impact tests (+Gz accelerations) were conducted by Hearon and Brinkley to evaluate the spinal injury potential of several seat cushions (ACES II, F-111, and different rate-dependent foam cushions such as Temper and Confor foams) compared to a baseline no-cushion condition [5]. The rate-dependent foam cushions were being evaluated due to their unique ability to provide a comfortable seating surface and to minimize the amplification of the impact acceleration pulse such as that experienced during an ejection. The ACES II cushion had a single thin layer of Temper foam, which has energy absorption properties. Test results indicated that the rate-dependent foam cushions transmitted less energy than the tested operational cushions, potentially decreasing the probability of spinal injury during ejection. The program aptly demonstrated the principle that human impact response is dependent upon the structural properties of the seat cushion.

In 1986 and 1987, additional tests were conducted by Brinkley, Perry, Orzech and Salerno to evaluate a proposed seat cushion to replace the existing cushion for the ejection seat in the F-4 aircraft [1]. The proposed F-4 cushion was compared to the existing cushion and to the current ACES II seat cushion. The current F-4 cushion was contoured, while the proposed F-4 cushion and the ACES II cushion were flat. The proposed cushion was composed of a rate-dependent foam, while the current F-4 cushion and the ACES II cushion were composed of multiple layers of different types and grades of foam. The ACES II cushion had a thin layer of Temper foam as previously tested in 1985. Results were similar to the previous study, indicating that the current F-4 cushion did not perform as well as the proposed F-4 rate-dependent foam cushion or the ACES II cushion in terms of impact protection.

In 1996, a series of vertical impact tests were conducted by Perry to evaluate a proposed seat cushion to be used with the ACES II ejection seat in the B-2 aircraft [9]. The test results showed that the human response to a +Gz impact with the proposed ACES II seat cushion in the B-2 aircraft was not significantly different from the response with no cushion or with the ACES II seat cushion currently used in the B-2 aircraft. The design changes, which consisted of a contoured seat cushion, use of different foam thicknesses, and the use of multiple layers of different rate-dependent foams, did not increase the current risk of injury associated with the present cushion within the limits tested. The rate-dependent foams performed as expected by limiting and controlling the biodynamic response. In addition, the test subjects noted an enhancement in the short-duration sitting comfort when using the proposed seat B-2 cushion.

This report documents the vertical impact evaluation of a proposed seat cushion to be used in the ejection seat of the B-52 aircraft. The proposed cushion was developed to provide optimal sitting comfort while minimizing energy transmission to the crewmember during the catapult phase of ejection.

3.0 METHODOLOGY

A series of +Gz vertical impact tests were conducted by AFRL/RHPA using a vertical deceleration tower to evaluate the proposed seat cushion to be used with the B-52 ejection seat. The tests exposed both the existing and the proposed B-52 cushion to the simulated catapult shock of a B-52 ejection seat. Tests were also conducted with no seat cushion for a baseline comparison. The test matrix is shown in Table 1 with five tests conducted with each of two manikins per configuration. The critical issues for the test program were to evaluate biodynamic response of manikins during +Gz impacts with seat cushion and no-cushion configurations and to determine if the proposed cushion changes the current risk of spinal injury for the B-52 ejection seat.

Table 1. B-52 Seat Cushion +Gz Impact Test Matrix

TEST CELL	NO. OF TESTS	SEAT CUSHION
A	**10**	**No Cushion**
B	**10**	**Current B-52**
C	**10**	**Proposed B-52**

The current cushion is a slightly contoured 1.5 in. thick polyethylene-grade foam inside a Nomex cover. The proposed seat cushion is deeply contoured, approximately 3 in. thick along the edges, and 1.5 to 2 in. thick at the ischial tuberosity contact point. The proposed cushion is composed of multiple layers of rate-dependent and polyurethane foams, and was covered on the top surface by a layer of black sheepskin. The cushions are shown on the VDT in Figures 1 and 2.

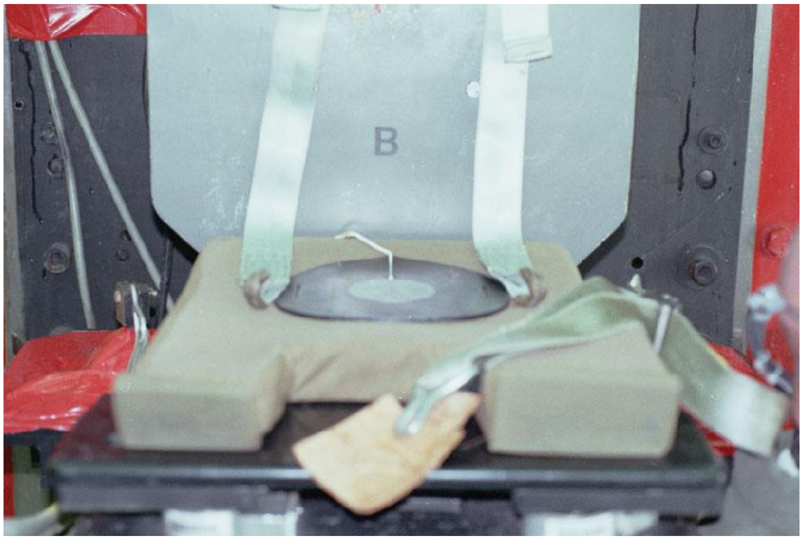

Figure 1. Front View of Current B-52 Ejection Seat Cushion

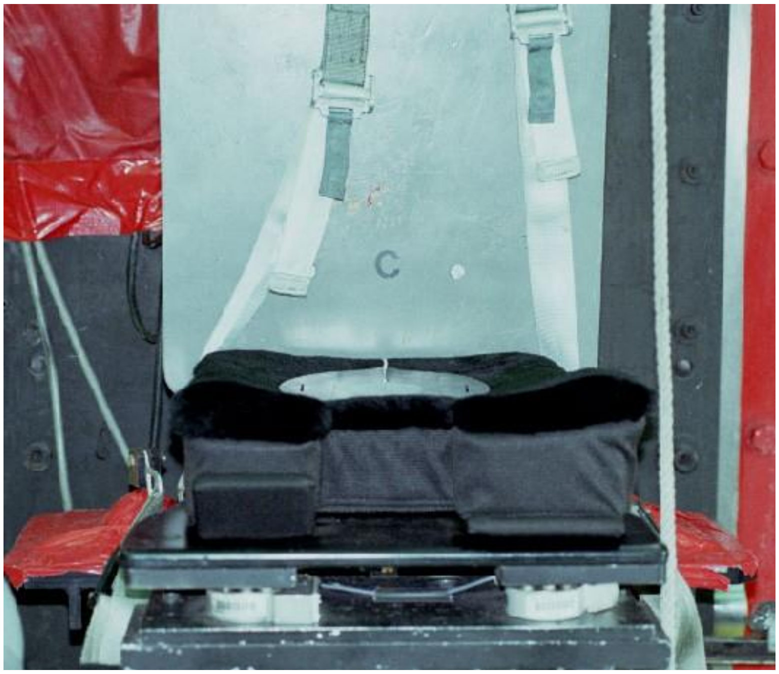

Figure 2. Front View of Proposed B-52 Ejection Seat Cushion

The vertical impacts were conducted on the AFRL/RHPA Vertical Deceleration Tower (VDT) shown in Figure 3. The VDT impact facility is composed of two vertical rails and a drop carriage. A generic test seat is attached to the vertical face of the carriage in an upright position. To conduct a vertical impact test, the carriage is raised to a determined drop height from a resting position. It is then released and allowed to enter a free-fall guided by the rails. A plunger mounted on the rear of the carriage is guided into a floor-mounted cylinder that is located between the vertical rails and filled with water. A +Gz pulse is imparted to the carriage when water is displaced from the cylinder by the plunger. The shape of the output acceleration pulse is controlled by varying the drop height, which determines the peak G level, and by varying the shape of the plunger, which determines the rise time. The plunger for all the tests was plunger #102.

Figure 3. AFRL/RHPA Vertical Deceleration Tower

All the vertical impact tests were conducted with a pulse that produces a human dynamic response equivalent to that generated during the catapult phase of the B-52 ejection seat. All the tests were conducted with the flat seat back perpendicular to the flat seat pan and with the impact vector in-line with the seat back. The configurations requiring seat cushions had the cushion positioned on the seat pan with the rear of the cushion flush against the seat back. The cushion was held in place with four strips of Velcro.

The test subjects for this test program were two different-sized manikins representative of the smallest and largest crewmembers that can fly current USAF B-52 aircraft. The nude weight of the small LOIS manikin was 103 lb and the nude weight of the Large ADAM manikin was 217 lb. Each manikin was dressed in a flight suit, wore an HGU-55/P flight helmet with a Thermal Plastic Liner (TPL) weighing approximately 2.5 lb, and was restrained with a standard USAF double shoulder strap and lap belt combination. The restraint system was pretensioned to 20 ± 5 lb for each test. The manikin's arms were restrained on the upper legs using Velcro straps. The lower legs of the manikin were also restrained with Velcro straps to the front of the seat. Five tests were conducted with each manikin in each of the three test configurations for a total of 30 impacts. The pre-impact position of the manikin subjects is shown in Figure 4.

Figure 4. Front and Side View of Pre-test Setup with Large ADAM

The manikins were instrumented to measure linear and angular accelerations of the head and chest and to measure forces and torques in the lumbar spine. Specific instrumentation consisted of three linear accelerometers and one angular accelerometer mounted in the headform, three linear acclerometers mounted in the chest, and a Denton 6-axis load cell mounted in the lumbar region to record loads due to the mass of the upper torso.

The "right hand" coordinate system shown in Figure 5 was used for channel setup on all tests. Transducer signal processing, including excitation, amplification, filtering, and transmission was provided onboard the VDT carriage by the Pacific Instruments Automatic Data Acquisition System (ADACS). Sampling for all channels was at 1000 samples per second. Each test was visually documented using the KODAK high-speed video system running at 500 frames per second. The KODAK system was mounted onboard the VDT test carriage.

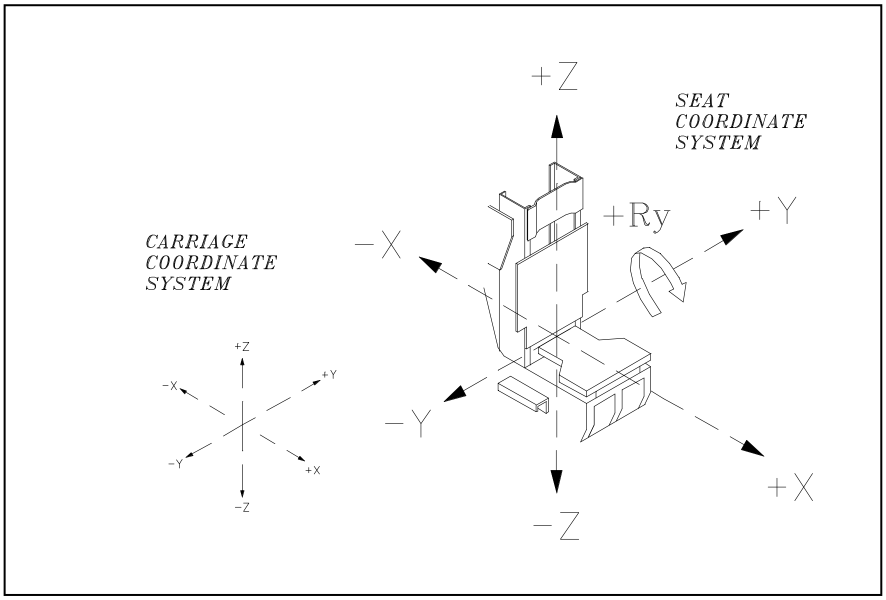

Figure 5. VDT Coordinate System

The z-axis sensor used on the top surface of the seat cushion was unique and had not been used in the previously referenced test programs. The sensor has been successfully used during ejection seat tests from a rocket-powered sled to measure the transmitted catapult acceleration from the seat structure through the ejection seat cushion. The accelerometer is imbedded in an aluminum disk and surrounded by a hard rubber disk that tapers from the middle to the outside edge. The total diameter of the disk is approximately 6 inches. The sensor was fixed to the top surface of the seat cushion using Velcro. This sensor is shown positioned on the seat cushions in Figures 1 and 2.

For positive vertical impact, human tolerance is limited by vertebral compression fractures [2,5]. Therefore, the key response parameters in this study were the z-axis seat load, resultant seat load (which is generally indicative of vertebral column loading), z-axis lumbar load, resultant lumbar load, and the z-axis accelerations measured at the cushion and lumbar region. To limit the risk of spinal injury in a vertical acceleration environment, it is imperative that these response parameters be minimized.

4.0 RESULTS AND DISCUSSION

Test results from selected measured parameters are shown in Tables 2 and 3 for the Large ADAM and the LOIS manikin, respectively. The parameter mean and standard deviation are identified (n=5).

Table 2. Summary of Peak Acceleration and Load Data for Large ADAM

Response Parameter	No Cushion	Current B-52 Cushion	Proposed B-52 Cushion
Carriage Z Accel (G)	15.04 ± 0.05	14.77 ± 0.06	15.06 ± 0.09
Chest Z Accel (G)	25.42 ± 0.34	30.16 ± 0.26	28.91 ± 0.52
Lumbar Z Accel (G)	25.07 ± 0.54	30.20 ± 0.56	28.32 ± 0.49
Cushion Z Accel (G)	17.70 ± 0.27	18.62 ± 0.30	18.86 ± 0.15
Seat Pan Load (lb)	5986 ± 127	6953 ± 102	6427 ± 216
Lumbar Load (lb)	1856 ± 14	2276 ± 25	2211 ± 89

Table 3. Summary of Peak Acceleration and Load Data for LOIS

Response Parameter	No Cushion	Current B-52 Cushion	Proposed B-52 Cushion
Carriage Z Accel (G)	14.96 ± 0.13	14.79 ± 0.02	14.84 ± 0.08
Chest Z Accel (G)	20.88 ± 0.46	26.20 ± 0.19	21.61 ± 0.15
Lumbar Z Accel (G)	18.86 ± 0.70	24.54 ± 0.23	21.57 ± 0.24
Cushion Z Accel (G)	15.03 ± 0.07	17.47 ± 0.21	15.79 ± 0.13
Seat Pan Load (lb)	2241 ± 74	2664 ± 34	2416 ± 28
Lumbar Load (lb)	827 ± 38	1051 ± 47	850 ± 19

As shown in Table 2 for the Large ADAM, the mean peak values for the indicated parameters for the proposed B-52 seat cushion are less than or equivalent to the corresponding data for the current B-52 seat cushion. As shown in Table 3 for the LOIS, the mean peak values for the indicated parameters for the proposed B-52 seat cushion are all less than the corresponding data for the current cushion, but more significantly for the LOIS manikin than for the Large ADAM.

To substantiate these observations, a Student T-Test analysis was conducted on the five measured response variable data sets for each manikin. The null hypothesis was that the difference between the response with the current cushion and the response with the proposed cushion is zero. The level of significance chosen was $\alpha = 0.05$. The degrees of freedom, d_f, is defined as $d_f = n_1 + n_2 - 2$ where n is the number of tests from each of the two configurations being compared. A summary of the results for each manikin is shown in Tables 4 and 5.

Table 4. Student T-Test Summary for Large ADAM

Response Parameters	**Degrees of Freedom**	**T-Value**	**Significantly Different**
Chest Z Accel (G)	8	4.811	Yes
Lumbar Z Accel (G)	8	5.627	Yes
Cushion Z Accel (G)	8	-1.608	No
Seat Pan Load (lb)	8	4.924	Yes
Lumbar Load (lb)	8	1.564	No

Table 5. Student T-Test Summary for LOIS

Response Parameters	**Degrees of Freedom**	**T-Value**	**Significantly Different**
Chest Z Accel (G)	6	36.495	Yes
Lumbar Z Accel (G)	7	19.003	Yes
Cushion Z Accel (G)	8	15.209	Yes
Seat Pan Load (lb)	7	12.087	Yes
Lumbar Load (lb)	8	8.963	Yes

These results indicate that for a small occupant, represented by the LOIS manikin, the proposed B-52 seat cushion significantly reduced the biodynamic responses when compared to the responses with the current seat cushion. The results for a large occupant, represented by the large ADAM, also show a significant reduction of the biodynamic responses, but for only 3 of the 5 response parameters. The remaining two parameters (seat cushion acceleration and lumbar load) indicated no significant change in the response.

The measured acceleration data were also used to substantiate the observations of the average parameter response values by computing a Shock Transmissibility (ST) value. The ST value is the ratio of the peak output acceleration divided by the peak input acceleration. This value provides an indication of the amplification of the impact energy produced by the seat cushion. ST values larger than 1.0 indicate that the cushion amplifies the impact to some extent, with higher values indicating higher relative amplification. Conversely, an ST value less than 1.0 would indicate that the cushion absorbs the impact energy to some extent. The ST values are shown in Table 6, and are calculated using the following equation
Where:

ST = Shock Transmissibility
A_{SC} = Seat Cushion Acceleration
A_{SP} = Carriage Acceleration

$$ST = \frac{Peak\ A_{SC}}{Peak\ A_{SP}} \tag{1}$$

Table 6. Shock Transmissibility Values for Large ADAM and LOIS

Parameter	**Current B-52 Cushion**	**Proposed B-52 Cushion**
ST Values, Large ADAM	1.26 ± 0.02	1.25 ± 0.02
ST Values, LOIS	1.18 ± 0.01	1.06 ± 0.01

The ST value for the proposed cushion with the large ADAM was approximately 1.25, and the ST value for the current cushion was approximately 1.26. It would therefore be expected that a large occupant would be at slightly less risk for injury with the proposed cushion as compared to the risk with the current cushion. The lumbar load verifies this analysis of the measured acceleration data, with the proposed cushion generating about 3% less load than the lumbar load with the current cushion. The ST value for the proposed cushion with the LOIS was 1.06, and the ST value for the current cushion was 1.18. This difference in ST values indicates that the proposed cushion provides a greater degree of protection to the lumbar region than the current cushion. The lumbar load verifies this analysis with the proposed seat cushion generating about 20% less load than the lumbar load with the current cushion.

To evaluate the effects of the differences in measured accelerations and loads in terms of risk to the occupant during ejection, comparisons were made of the risk of spinal injury assuming a maximum B-52 ejection seat catapult acceleration of approximately 18 G. The risk of spinal injury was calculated using the Dynamic Response Index or DRI. The DRI is based on describing the biodynamic response of the human torso in terms of the displacement of the mass of a simple lumped-parameter, mass-spring-damper mechanical system [2]. The system can be represented by a second order differential equation, which can be used to calculate the magnitude of deflection in the human spinal column. The maximum value of the deflection relates the tolerance of the human spine to an impact acceleration pulse. The DRI is calculated as shown in Equation 2.
Where:

DRI = Dynamic Response Index

ω_n = Undamped natural frequency of the mass-spring-damper system

$$DRI = \frac{\omega_n{}^2 \delta}{g} \tag{2}$$

δ = Deflection of the mass with respect to the system's base

g = Acceleration due to gravity

A plot of the DRI as a function of the probability of a spinal injury due to a vertical impact acceleration is shown in Figure 3.

Assuming the 18 G seat pan acceleration, and knowing that the DRI matches the peak catapult acceleration for the B-52 catapult (Due to the time-to-peak of the B-52 catapult acceleration, the peak catapult or seat cushion acceleration and the DRI value are equivalent [10]), the calculations for peak acceleration that the occupant would experience at the buttocks using each of the seat cushion configurations, and the values for DRI as a function of the seat cushion acceleration, are shown in Table 7. The seat cushion acceleration values were calculated by multiplying the seat pan acceleration by the ST value for each configuration from Table 6. This assumes the ST value does not change as a function of the peak input acceleration.

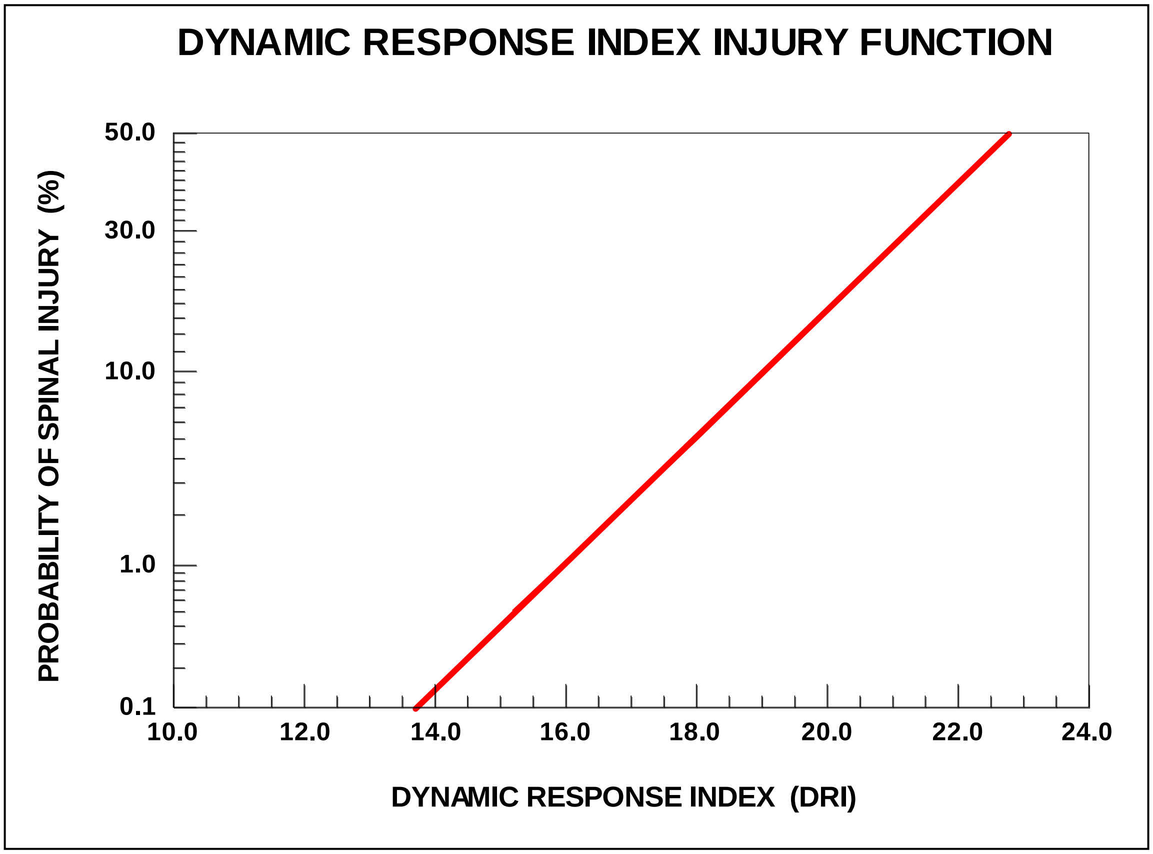

Figure 6. Plot of DRI as a Function of Spinal Injury Risk

Table 7. Comparison of Seat Cushion Acceleration and DRI Values for Large ADAM

Parameter	Current B-52 Cushion	Proposed B-52 Cushion
Assumed Seat Pan Accel. (G)	18.0	18.0
Calculated Seat Cushion Accel. (G)	22.68	22.5
Calculated Seat Pan DRI	18.0	18.0
Calculated Seat Cushion DRI	22.68	22.5

Table 8. Comparison of Seat Cushion Acceleration and DRI Values for LOIS

Parameter	Current B-52 Cushion	Proposed B-52 Cushion
Assumed Seat Pan Accel. (G)	18.0	18.0
Calculated Seat Cushion Accel. (G)	21.24	19.08
Calculated Seat Pan DRI	18.0	18.0
Calculated Seat Cushion DRI	21.24	19.08

Using Figure 6, the DRI values that were calculated in Table 4 shown above, were used to estimate the percent change in the probability of spinal injury as a function of the tested seat cushion configurations. The probability of injury, P(I), and the percent change are shown in Table 9.

Table 9. Probability of Spinal Injury for Each Cushion Configuration

Parameter	Current B-52 Cushion	Proposed B-52 Cushion	Percent Change
Probability of Injury, Large ADAM	42.9 %	40.3 %	-6.1%
Probability of Injury, LOIS	24.0 %	7.9 %	-67.1%

The data from Table 9 indicates that the proposed B-52 ejection seat cushion reduces the potential for spinal injury for both a small and large occupant. The risk reduction is much greater for a small occupant than for a large occupant. This finding agrees with the measured acceleration and load data which indicated that the proposed B-52 seat cushion limits the dynamic response of a small occupant to a greater degree than a large occupant when compared to the responses with the current B-52 seat cushion.

4.0 CONCLUSION

A series of vertical impacts were conducted with two different-sized instrumented manikins to evaluate the impact response of a proposed B-52 seat cushion to simulated B-52 ejection seat catapult accelerations. The input accelerations generated biodynamic responses similar to those generated by the actual B-52 catapult. Five tests were conducted with each manikin in each of three different configurations that included no cushion, current B-52 cushion, and proposed B-52 cushion.

Evaluation of the measured data indicates that the proposed seat cushion significantly reduced a majority of the evaluated biodynamic responses with the large manikin weighing 217 lb, and significantly reduced all the evaluated responses of the small manikin weighing 103 lb. The small manikin's lumbar loads were reduced by approximately 20%. A reduction in the biodynamic response (reaction loads and accelerations) would reduce the risk of spinal injury during vertical impact.

The risk of spinal injury was calculated for each cushion using the small and large manikin and an input acceleration of 18 G. The injury risk analysis agreed with the measured acceleration and load data analysis, with the proposed B-52 seat cushion reducing the risk of spinal injury for both small and large occupants by approximately 65% and 6% respectively, when compared to the risks with the current B-52 seat cushion.

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APPENDIX A.

TEST CONFIGURATION AND DATA ACQUISITION SYSTEM FOR VERTICAL IMPACT TESTS OF A PROPOSED B-52 SEAT CUSHION

(B52SC STUDY)
Study Number 200102

Prepared under Contract F41624-97-D-6004
CDRL A005

August 2001

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Introduction

Veridian Engineering Division prepared this report for the Air Force Research Laboratory, Human Effectiveness Directorate, Biodynamics and Acceleration Branch under Air Force contract F41624-97-D-6004. It describes the test facility, test configurations, data acquisition and analysis, and instrumentation procedures used for vertical impact tests of a Proposed B-52 Seat Cushion Program (B52SC Study, 200102). A series of impact tests were performed on the Vertical Deceleration Tower (VDT) located in Bldg 824 at Wright-Patterson AFB. An Advanced Dynamic Anthropomorphic Manikin (ADAM-L) weighing 217 lb and a Lightest Occupant in Service (LOIS) manikin weighing 103 lb were used in this test program.

Test Facility: Vertical Deceleration Tower

The AFRL/RHPA VDT (Figure A-1) was used for all of the tests. The facility consists of a 60-foot vertical steel tower, which supports a guide rail system, an impact carriage supporting a plunger, a hydraulic deceleration device and a test control and safety system. The impact carriage can be raised to a maximum height of 39 feet prior to release. After release, the carriage free-falls until the plunger, attached to the undercarriage, enters a water-filled cylinder mounted at the base of the tower. The subject experiences a deceleration impulse as the plunger displaces water in the cylinder. The deceleration profile is determined by the free-fall distance, the carriage and test specimen mass, the shape of the plunger and the size of the cylinder orifice. A rubber bumper is used to absorb the final impact as the carriage stops.

Figure A-1. VDT Facility

For these tests, plunger Number 102 was mounted under the carriage. The drop height was adjusted to provide the desired 15 G input pulse. The drop height was varied from 18’6” to 20’ during the course of the study to account for changes in the test environment (temperature, humidity). A total of 36 tests were completed on the VDT from 8 May 01 to 15 May 01.

The VDT generic seat fixture similar to the fixture shown in Figure A-2 was used for all tests. The seat back was mounted at an angle of 90° from the seat pan, which was parallel to the ground.

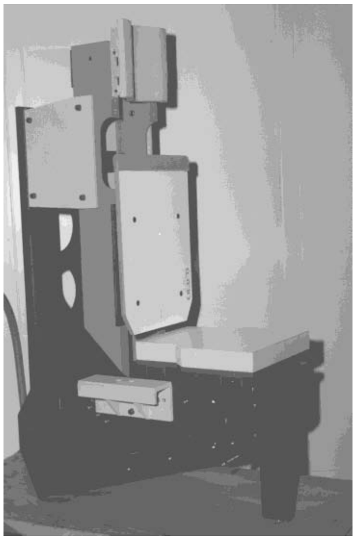

Figure A-2. VDT Generic Seat Fixture

The standard double shoulder strap and lap belt assembly was used as the restraint system for this series of tests. The pre-tension levels of the restraint system were 20 ± 5 lbs. Velcro limb restraints were used to restrain the manikin’s arms and legs. The manikin and restraint system test setup is shown in Figure A-3.

Figure A-3. Manikin and Restraint Assembly

Test Matrix

A large ADAM-L (217-lb) manikin and a LOIS (103-lb) manikin were tested at the conditions shown in the Test Matrix (Table A-1). The acceleration waveform for the VDT was an approximate half-sine wave with a peak of 15 G and a time to peak of approximately 80 msec. Several parameter verification tests were completed prior to collection of manikin data. The manikins were tested in the seated posture and restrained to the seat using a harness designed for the VDT. Five (5) tests were conducted in each cell.

Table A-1. Test Matrix

Cell	Peak Acceleration (G)	Cushion
A	15	None
B	15	B-52 Baseline
C	15	Proposed B-52

Instrumentation

Accelerometers and load transducers were chosen to provide the optimum resolution over the expected test load range. Full-scale data ranges were chosen to provide the expected full-scale range plus 50% to assure the capture of peak signals. All transducer bridges were balanced for optimum output prior to the start of the program. The accelerometers were adjusted for the effect of gravity in software by adding the component of a 1 G vector in line with the force of gravity that lies along the accelerometer axis.

The accelerometer and load transducer coordinate systems are shown in Figure A-4. The seat coordinate system is right-handed with the z-axis parallel to the seat back and positive upward. The x-axis is perpendicular to the z-axis and positive eyes forward from the subject. The y-axis is perpendicular to the x and z-axes according to the right-hand rule.

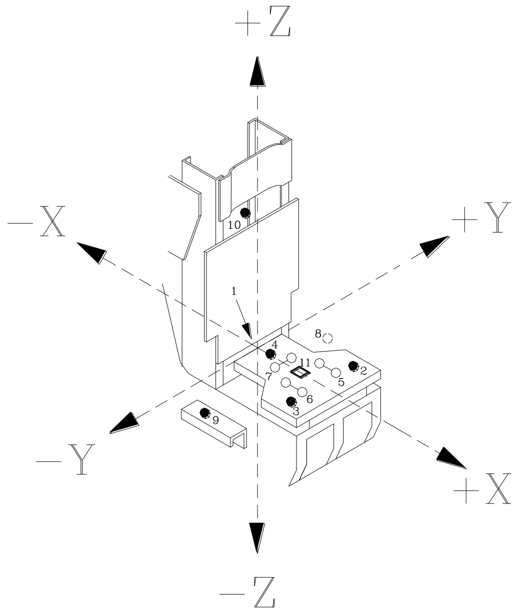

Figure A-4. Coordinate System

Table A-2. Transducer Location Measurements

Point	X-Location in (cm)	Y-Location in (cm)	Z-Location in (cm)	Description
1	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	SEAT REFERENCE POINT
2	17.90 (45.46)	5.00 (12.70)	-1.22 (-3.10)	LEFT SEAT Z FORCE
3	17.90 (45.46)	-5.00(-12.70)	-1.22 (-3.10)	RIGHT SEAT Z FORCE
4	6.68 (16.96)	0.00 (0.00)	-1.22 (-3.10)	CENTER SEAT Z FORCE
5	10.00 (25.41)	6.00 (15.25)	-1.85 (-4.70)	LEFT SEAT X FORCE
6	10.00 (25.41)	-6.00 (-15.25)	-1.85 (- 4.70)	RIGHT SEAT X FORCE
7	9.26 (23.51)	1.99 (5.05)	-1.85 (-4.70)	CENTER SEAT Y FORCE
8	0.81 (2.06)	9.00 (22.86)	-1.61 (-4.10)	LEFT LAP BELT FORCE
9	0.81 (2.06)	-9.00 (-22.86)	-1.61 (-4.10)	RIGHT LAP BELT FORCE
10	-5.47 (-13.90)	0.00 (0.00)	27.39 (69.58)	SHOULDER FORCE
11	12.33 (31.31)	0.00 (0.00)	-1.69 (-4.30)	X, Y, Z ACCELERATION

The origin of the seat coordinate system is designated as the seat reference point (SRP). The SRP is at the midpoint of the line segment formed by the intersection of the seat pan and seat back (see point #1, Table A-2). All vector components (for accelerations, angular accelerations, forces, moments, etc.) were positive when the vector component (x, y and z) was in the direction of the positive axis.

The linear accelerometers were wired to provide a positive output voltage when the acceleration experienced by the accelerometer was applied in the +x, +y and +z directions. The load cells and load links were wired to provide a positive output voltage when the force exerted by the load cell on the subject was applied in the +x, +y or +z direction. The angular Ry accelerometers were wired to provide a positive output voltage when the angular acceleration experienced by the angular accelerometer was applied in the +y direction according to the right-hand rule. The manikin lumbar load cells were wired to provide a positive output voltage when the force exerted by the load cell on the lumbar was applied in the +x, +y or +z direction. The manikin torque transducers were wired to provide a positive output voltage when the torque experienced by the transducer was applied in the +x, +y or +z direction. All transducers, except the carriage accelerometers and the carriage velocity tachometer, were referenced to the seat coordinate system. The carriage tachometer was wired to provide a positive output voltage during free-fall. The carriage accelerometers were referenced to the carriage coordinate system.

The seat accelerometer location was measured at the center of the accelerometer block. The locations of the load cells that anchor the harness were measured at the point where the harness is attached to the load cell. The locations of the other loads cells were measured at the point on the load cell where the external force is applied.

Carriage velocity was measured using a Globe Industries tachometer (Model 22A672-2). The rotor of the tachometer was attached to an aluminum wheel with a rubber "O" ring around its circumference to assure good rail contact. The wheel contacted the track rail and rotated as the carriage moved, producing an output voltage proportional to the velocity.

Load Cell Transducers

Shoulder/anchor forces were measured using a mix of available load cells. Specific sensors are listed by channel in the Test Setup and Calibration Log. The load parameters measured are indicated below:

Shoulder x, y and z force
Seat Pan x, y, and z force
Head Rest x force
Left lap belt x, y and z force
Right lap belt x, y and z force.

The lap/vertical anchor force triaxial load cells were located on separate brackets mounted on the side of the seat frame parallel to the seat pan. The shoulder strap force triaxial load cell was mounted on the seat frame between the seat back support plate and the headrest. The load transducer locations are shown in Figure A-4.

Left, right and center seat forces were measured using three load cells and three load links. The three load cells were Strainsert Model FL2.5U-2SPKT. The three load links (Figure A-5) used Micro Measurement Model EA-06-062TJ-350 strain gages. All measurement devices were located under the seat pan support plate. The load links were used for measuring loads in the x and y directions, two in the x direction and one in the y direction. Each load link housed a swivel ball, which acted as a coupler between the seat pan and load cell mounting plate. The Strainsert load cells were used for measuring loads in the z direction.

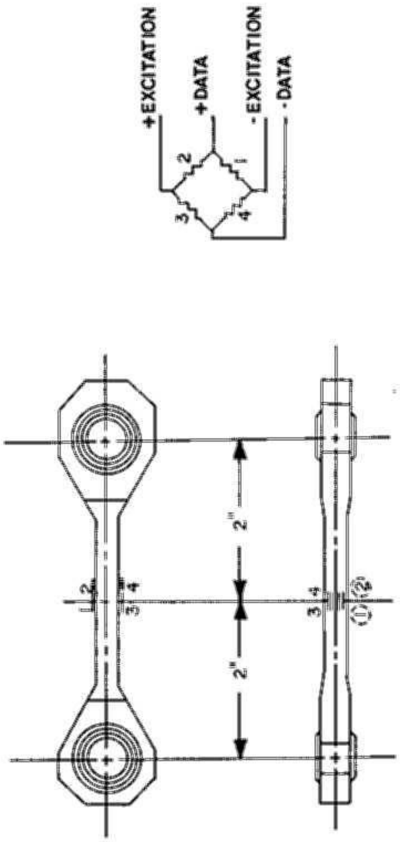

Figure A-5. Load Links

Accelerometers

A z-axis accelerometer was mounted in a thin rubber disk and placed on top of the seat cushion for all tests. This accelerometer is commonly used in vibration studies where it is referred to as a Ride Quality Meter (Figure A-6). Carriage z acceleration was measured using one Endevco Model 2262A-200 linear accelerometer. The accelerometer was mounted on a small acrylic block and located behind the seat on the VIP seat structure. Additional linear accelerometers were used to measure acceleration at the seat pan. They were attached to a 1 x 1 x ¾-inch acrylic block and were mounted near the center of the load cell mounting plate.

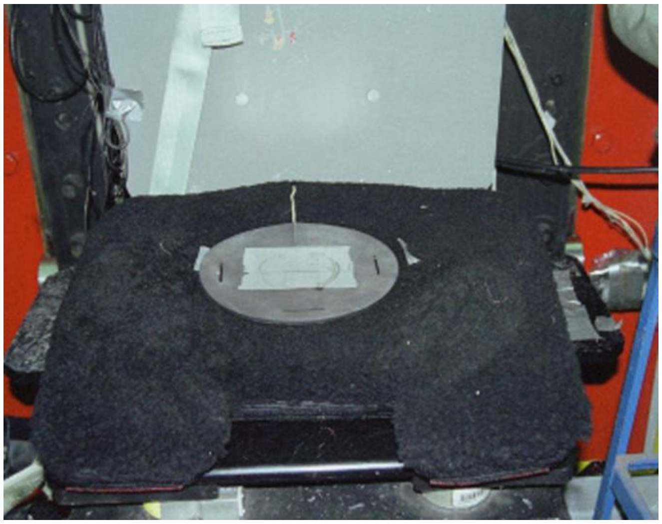

Figure A-6. Ride Quality Meter

The specific accelerometers used are listed by type and impact axis in the Program Setup and Calibration Logs. The logs also provide individual sensor serial numbers, model numbers, channel assignments and sensor sensitivities. The tables also provide channel assignments and sensor sensitivities. The x-axis accelerometer was used in the first phase of tests only.

Transducer Calibration

Calibrations were performed before and after testing to confirm the accuracy and functional characteristics of the transducers. Pre-program and post-program calibrations are given in the Test Setup and Calibration Log. The Precision Measurement Equipment Laboratories (PMEL) at Wright-Patterson Air Force Base calibrated all Strainsert load cells. PMEL calibrated these devices on a regular basis and provided current sensitivity and linearity data.

The comparison method (Ensor, 1970) was used to calibrate the laboratory accelerometers. A laboratory standard accelerometer, calibrated on a yearly basis by Endevco with standards traceable to the National Bureau of Standards, and a test accelerometer were mounted on a shaker table. A random noise generator drove the shaker table and the accelerometer output were collected. The frequency response and phase shift of the test accelerometer was determined by using Fourier analysis on an MS-DOS PC computer. The natural frequency and the damping factor of the test accelerometer were determined, recorded and compared to previous calibration data for that test accelerometer. Sensitivities were calculated at 40 G and 100 Hertz. The sensitivity of the test accelerometer was determined by comparing its output to the output of the standard accelerometer.

Veridian calibrated the shoulder/lap triaxial load cells and load links. These transducers were calibrated to a laboratory standard load cell in a special test fixture. The sensitivity and linearity of each test load cell were obtained by comparing the output of the test load cell to the output of the laboratory standard under identical loading conditions. The laboratory standard load cell, in turn, is calibrated by PMEL on a regular basis.

The angular accelerometers are calibrated on a pre- and post-study basis by comparing their output to the output of a linear standard accelerometer. The angular sensors are mounted parallel to the axis of rotation of a Honeywell low inertia DC motor. The linear sensor is mounted perpendicular to the axis of rotation. An alternating current is supplied to the motor, which drives a constant sinusoidal angular acceleration of 100 Hz. The sensitivity of the angular accelerometer is calculated from the RMS output voltage to match the angular value computed from the linear standard.

Veridian regularly calibrates the velocity wheel by rotating it at approximately 2000, 4000 and 6000 revolutions per minute (RPM) and recording both the output voltage and the RPM.

Data Acquisition

The Master Instrumentation Control Unit in the Instrumentation Station controls data acquisition. Using a comparator, a test was initiated when the countdown clock reached zero. The comparator is set to start data collection at a pre-selected time. All data were collected at 1000 samples per second and filtered at a 120 Hz cutoff frequency using an 8-pole Butterworth filter.

Prior to placing a subject in the seat, data were recorded to establish a zero reference for all transducers. The reference data were stored separately from the test data and were used in the processing of the test data. A reference mark pulse was generated to mark the Model 5600A electronic data at a pre-selected time after test initiation to place the reference mark close to the impact point. The reference mark time was used as the start time for data processing of the electronic data.

The Model 5600A Portable Data Acquisition System (DAS), manufactured by Pacific Instruments, was used for this test program. The Model 5600A DAS is a ruggedized, DC powered, fully programmable signal conditioning and recording system for transducers and events. The Model 5600A DAS is designed to withstand a 50G shock in any direction. The Model 5600A DAS is housed in two units and its installation on top of the seat carriage is shown in Figure A-7.

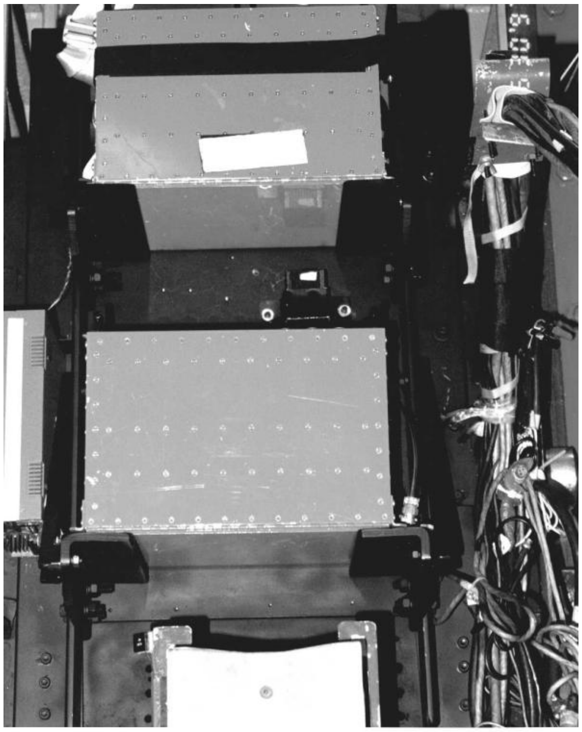

Figure A-7. Pacific Instruments 5600A DAS

Each of the two units can accommodate up to 28 transducer channels and 32 events. The signal conditioning system accepts a variety of transducers including full and partial bridges, voltage, and piezoresistive. Transducer signals are amplified, filtered, digitized and recorded in onboard solid-state memory. The transducer signals for the B52SC Study were acquired at 1,000 samples/sec and filtered at 120 Hz.

The data acquisition system is controlled through an IEEE-488.1 interface using the GPIB instruction language.

A desktop PC with an AT-GPIB board configures the 5600A DAS before testing and retrieves the data after each test. The PC stores the raw data and then passes it on to a DEC Alpha computer for processing and output to permanent storage and printouts.

The program ‘TDR5600’ on the PC handles the interface with the Model 5600A DAS. It includes options to compute and store zero reference voltage values; collect and store a binary zero reference data file; compute and display preload values; and collect and store binary test data. The program communicates over the GPIB interface.

Test data can be reviewed after it is converted to digital format using the "quick look" SCAN_EME routine on the PC. SCAN_EME produced a plot of the data stored for each channel as a function of time. The routine determined the minimum and maximum values of each data plot. It also calculates the rise time, pulse duration, and carriage acceleration, and creates a disk file containing significant test parameters.

The high speed RS-422 board installed in the Gateway 486 computer communicates with the 5600A DAS with a transfer rate of 1 Mbit/sec. The Gateway 486 computer configured the DAS before the test and retrieved the test data from the onboard memory in the DAS after the test was completed. The test data were later transferred to the DEC 800 5/333 Alpha AXP through the Ethernet network and output to optical disk for permanent storage.

The C program ADASEME on the Gateway 486 computer configured the DAS prior to the start of the test, transferred test data from the DAS when the test is completed, and stored the collected test data in a binary data file. The program is organized into 5 menu options. The menu options are: test setup, diagnostics, transducer calibration, test data conversion, view graphs, and test data collection. The program communicated with the DAS by sending instructions over the RS-422 interface.

KODAK High Speed Video

A Kodak Ektapro 2000 color video system was used to collect digital video images of the impact events. The Kodak video system combines high-rate image collection and excellent resolution digital imaging within a small, rugged, self-contained package. The images were collected at 500 frames/second. The video files were downloaded to video-tape, converted to AVI format, and placed in the HEPA Biodynamic Database.

Data Processing

The Excel 2000 Workbook B52scVdt.xls was used to analyze the TDR5600 DAS test data from the B52SC Study (Vertical Deceleration Tower Facility). B52scVdt.xls contains the Visual Basic module Module1 and the forms UserForm1 and UserForm2. Module1 contains one main subroutine that calls numerous other subroutines and functions. B52scVdt.xls calls the DLL functions in the Dynamic Link Libraries ScanDll1, Mathdll and FortranMathDll. The shortcut ctrl+r can be used to execute the Visual Basic module. The Visual Basic module displays the two user forms.

UserForm1 requests the user to enter the system acronym, study description, impact channel number, magnitude of the impact start level, start time, processing time, T0 bit number and reference mark bit number. The user has the option to find the Kodak start time, start at the reference mark time, and use the processing time as the impact window time. The user has the option to plot the channels, print out the summary sheet, print out the plots, update the Access database information for the Biodynamic Data Bank, and create an Excel time history workbook for the Biodynamic Data Bank. Default values are displayed based on the last test that was analyzed. The default values are stored in worksheet “Defaults” inside the workbook.

UserForm2 requests the user to enter the test number for each test to be processed. The default test parameters are retrieved from the test sensitivity file and displayed on the form. The user may specify new values for any of the displayed test parameters. The test parameters include the subject ID, weight, age, height and sitting height. Additional parameters include the cell type, nominal g level, subject type (manikin or human) and belt preload status (computed or not computed).

The workbook contains worksheets named “Channels,” “Formulas,” “Preloads,” “Plots,” “Time History File,” “Plot Pages,” and “Defaults”. The “Channels” worksheet contains the channel number, channel name, database ID number, channel description, and summary sheet description for each channel. The “Formulas” worksheet contains Excel formulas and Excel functions. The “Preloads” worksheet contains the preload numbers and descriptions. The “Plots” worksheet contains the channel name, the plot description, and the plot vertical axis minimum, maximum and increment for each channel to be plotted. The “Time History File” worksheet defines the channel names for the time history files (the database time history files do not use this worksheet). The “Plot Pages” worksheet allows the user to print out selected plot pages (by default, all plot pages are printed).

B52scVdt generates time histories for the carriage x, y and z axis accelerations; the carriage velocity; the seat pan x, y and z axis accelerations; the seat pan z DRI; the seat cushion z and lumbar z accelerations; the seat cushion z DRI; the head x, y, z, Ry and resultant accelerations; the chest x, y, z, Ry and resultant accelerations; the upper and lower headrest x axis forces and their sum; and the shoulder x, y, z and resultant forces. Time histories are also generated for the left and right lap x, y and z axis forces and resultants; the left, right and center seat back x axis forces and their sum; the seat back y force; the left and right seat back z axis forces and their sum; the tare corrected seat back z sum; the seat back resultant force; the tare corrected seat back resultant force; the left and right seat pan x axis forces and their sum; the seat pan y force; the left, right and center seat pan z axis forces and their sum; the tare corrected seat pan z sum; the seat pan resultant force; the tare corrected seat pan resultant force; the total body x, y, z and resultant forces; the lumbar x, y, z and resultant forces; and the lumbar x, y, z and resultant torques. The lumbar z, seat cushion z and seat pan z accelerations were filtered at 60 Hz using the IIR Butterworth filter algorithm contained in SAE J211.

Values for the preimpact level and the extrema for each time history are stored in the Excel worksheet summary file and printed out as a summary sheet for each test. The time histories are also plotted with up to six plots per page. The user has the option to create test summary information and Excel workbooks containing the time histories for the Biodynamic Data Bank.

Test Setup and Calibration Log

PROGRAM:	DYNAMIC TESTING OF B-52 SEAT CUSHION (B52SC)	TEST DATES:	7 MAY 2001 - 15 MAY 2001
		TEST NUMBERS:	4319 - 4354
STUDY NUMBER:	200102	SAMPLE RATE:	1K
FACILITY:	VERTICAL DROP TOWER	FILTER FREQUENCY:	120
DATA COLLECTION SYSTEM:	PACIFIC INSTRUMENTS	TRANSDUCER RANGE (VOLTS):	10 v

DATA CHAN.	DATA POINT	TRANSDUCER MFG. & MODEL	SERIAL NUMBER	PRE-CAL		POST-CAL		% D	EXC. VOL.	AMP GAIN	FULL SCALE	NOTES
				DATE	SENS	DATE	SENS					
0	VELOCITY	GLOBE 22A672-2	4	14-Mar-01	.152 v/ft/sec	21-May-01	.154 v/ft/sec	1.3	10 V	1	65.8 FT/SEC	Raw sensitivity=.1745 v/rev/sec; (12in/ft / 4.44 in/rev) x .1745 v/r/s = .4717 rev/ft; Atten @ 3.094; .4717 v/ft x (1/ 3.094) = .1524v/ft/sec
1	CARRIAGE X ACCEL (G)	ENDEVCO 7264-200	CC99H	8-Mar-01	2.9949 mv/g	21-May-01	2.9949 mv/g	.1	10 V	100	33.4 G	
2	CARRIAGE Y ACCEL (G)	ENDEVCO 2262A-200	CC86H	8-Mar-01	2.8054 mv/g	21-May-01	2.8040 mv/g	-.1	10 V	200	17.8 G	
3	CARRIAGE Z ACCEL (G)	ENDEVCO 2262A-200	MH82	8-Mar-01	2.0644 mv/g	21-May-01	2.0574 mv/g	-.3	10 V	100	48.4	
4	SEAT PAN X ACCEL (G)	ENTRAN EGE-72-200	93C93C19-R08	8-Mar-01	2.1719 mv/g	21-May-01	2.1620 mv/g	-.5	10 V	200	23 G	
5	SEAT PAN Y ACCEL (G)	ENTRAN EGE-72-200	93C93C19-R13	8-Mar-01	2.3246 mv/g	21-May-01	2.3373 mv/g	.5	10 V	200	21.5 G	
6	SEAT PAN Z ACCEL (G)	ENTRAN EGE-72-200	93C93C19-R10	8-Mar-01	2.1634 mv/g	21-May-01	2.1662 mv/g	.1	10 V	100	46.2 G	
7	LEFT SEAT PAN X FORCE (LB)	AAMRL / DYN LOAD LINK	2	13-Mar-01	-10.91 uv/lb	16-May-01	10.63 uv/lb	-2.6	10 V	1000	916.6 LB	USE NEGATIVE SENSITIVITY
8	RIGHT SEAT PAN X FORCE (LB)	AAMRL / DYN LOAD LINK	1	13-Mar-01	11.16 uv/lb	16-May-01	10.94 uv/lb	-2	10 V	1000	896.1 LB	
9	SEAT PAN Y FORCE (LB)	AAMRL / DYN LOAD LINK	3A	13-Mar-01	10.62 uv/lb	16-May-01	10.90 uv/lb	2.6	10 V	1000	941.6 LB	
10	LEFT SEAT PAN Z FORCE (LB)	STRAINCERT FL2.5U-2SPKT	Q-3294-4	12-Mar-01	-7.87 uv/lb	16-May-01	8 uv/lb	1.6	10 V	200	6353.2 LB	USE NEGATIVE SENSITIVITY

11	RIGHT SEAT PAN Z FORCE (LB)	STRAINCERT FL2.5U-2SPKT	Q-3294-3	12-Mar-01	-7.94 uv/lb	16-May-01	8.01 uv/lb	.8	10 V	200	6297.2 LB	USE NEGATIVE SENSITIVITY
12	CENTER SEAT PAN Z FORCE (LB)	STRAINCERT FL2.5U-2SPKT	Q-3294-5	21-Jul-00	-7.92 uv/lb	16-May-01	7.99 uv/lb	.9	10 V	200	6313.1 LB	USE NEGATIVE SENSITIVITY
13	LEFT SEAT BACK X FORCE (LB)	STRAINSERT FL1U-2SGKT	Q-3008-2	20-Jul-00	-19.66 uv/lb	16-May-01	19.66 uv/lb	0	10 V	500	1017.3 LB	USE NEGATIVE SENSITIVITY
14	RIGHT SEAT BACK X FORCE (LB)	STRAINSERT FL1U-2SGKT	Q-3008-1	20-Jul-00	-19.68 uv/lb	16-May-01	19.83 uv/lb	0.8	10 V	500	1016.3 LB	USE NEGATIVE SENSITIVITY
15	CENTER SEAT BACK X FORCE (LB)	STRAINSERT FL1U-2SGKT	Q-3008-3	20-Jul-01	-19.74 uv/lb	16-May-01	19.92 uv/lb	0.9	10 V	500	1013.2 LB	USE NEGATIVE SENSITIVITY
16	LEFT SEAT BACK Z FORCE (LB)	AAMRL / DYN LOAD LINK	9	12-Mar-01	-11.21 uv/lb	16-May-01	11.39 uv/lb	1.6	10 V	1000	892.1 LB	USE NEGATIVE SENSITIVITY
17	RIGHT SEAT BACK Z FORCE (LB)	AAMRL / DYN LOAD LINK	8	12-Mar-01	-10.90 uv/Lb	16-May-01	11.01 uv/lb	1	10 V	1000	917.4 LB	USE NEGATIVE SENSITIVITY
18	SEAT BACK Y FORCE (LB)	AAMRL / DYN LOAD LINK	10	12-Mar-01	-10.41 uv/lb	16-May-01	10.56 uv/lb	1.4	10 V	1000	960.6 LB	USE NEGATIVE SENSITIVITY
19	LEFT LAP X FORCE (LB)	MICH-SCI 4000	4	13-Mar-01	-13.46 uv/lb	17-May-01	13.57 uv/lb	.8	10 V	500	1585.9 LB	USE NEGATIVE SENSITIVITY
20	LEFT LAP Y FORCE (LB)	MICH-SCI 4000	4	13-Mar-01	13.89 uv/lb	17-May-01	13.83 uv/lb	-.4	10 V	500	1439.9 LB	
21	LEFT LAP Z FORCE (LB)	MICH-SCI 4000	4	13-Mar-01	13.50 uv/lb	17-May-01	13.21 uv/lb	-2.2	10 V	500	1481.5 LB	
22	RIGHT LAP X FORCE (LB)	MICH-SCI 4000	5	13-Mar-01	-13.71 uv/lb	17-May-01	13.66 uv/lb	-.4	10 V	500	1458.8 LB	USE NEGATIVE SENSITIVITY
23	RIGHT LAP Y FORCE (LB)	MICH-SCI 4000	5	13-Mar-01	14.23 uv/lb	17-May-01	14.22 uv/lb	-.1	10 V	500	1405.5 LB	
24	RIGHT LAP Z FORCE (LB)	MICH-SCI 4000	5	13-Mar-01	13.81 uv/lb	17-May-01	13.61 uv/lb	-1.5	10 V	500	1448.2 LB	
25	SHOULDER X FORCE (LB)	MICH-SCI 4000 (Z)	2	13-Mar-01	13.60 uv/lb	17-May-01	13.41 uv/lb	-1.4	10 V	500	1470.6 LB	

26	SHOULDER Y FORCE (LB)	MICH-SCI 4000	2	13-Mar-01	13.43 uv/lb	17-May-01	13.60 uv/lb	1.3	10 V	500	1489.2 LB	
27	SHOULDER Z FORCE (LB)	MICH-SCI 4000 (X)	2	13-Mar-01	-14.05 uv/lb	17-May-01	14.21 uv/lb	1.1	10 V	500	1423.5 LB	USE NEGATIVE SENSITIVITY
28	EVENT / T=0								0			BIT 0 IS EVENT. BIT 1 IS T=0.
29	UPPER HEADREST X FORCE (LB)	STRAINCERT FL1U-2SPKT	Q-3541-1	19-Jul-00	-19.64 uv/lb	16-May-01	19.54 uv/lb	-.5	10 V	1000	509.2 LB	USE NEGATIVE SENSITIVITY
30	LOWER HEADREST X FORCE (LB)	STRAINCERT FL1U-2SPKT	Q-3541-2	20-Jul-00	-19.75 uv/lb	16-May-01	19.84 uv/lb	.4	10 V	1000	506.3 LB	USE NEGATIVE SENSITIVITY
31	SEAT CUSHION Z ACCEL (G)	ENTRAN EGE-72-200	93C93C19-R12	20-Mar-01	2.2893 mv/g	21-May-01	2.3006 mv/g	.5	10 V	100	43.7 G	
32	INT HEAD X ACCEL (G)	ENTRAN EGA-125F-100D	93F93F11-P19	8-Jan-01	1.9725 mv/g	21-May-01	1.9612 mv/g	-.6	10 V	100	50.7 G	USED FOR ADAM TESTS 4335 to 4354. USE NEGATIVE SENSITIVITY.
32	INT HEAD X ACCEL (G)	ENTRAN EGV3-F-250	97C97C27 TB06	8-Jan-01	.905 mv/g	22-May-01	.9078 mv/g	.3	10 V	100	110.5 G	USED FOR LOIS TESTS 4319 to 4334.
33	INT HEAD Y ACCEL (G)	ENTRAN EGA-125F-100D	96E95C07-R04	8-Jan-01	-1.6402 mv/g	21-May-01	1.6233 mv/g	-1	10 V	100	61 G	USED FOR ADAM TESTS 4335 to 4354. USE NEGATIVE SENSITIVITY.
33	INT HEAD Y ACCEL (G)	ENTRAN EGV3-F-250	97C97C27 TB06	8-Jan-01	-.9417 mv/g	22-May-01	.9488 mv/g	.8	10 V	100	106.2 G	USED FOR LOIS TESTS 4319 to 4334. USE NEGATIVE SENSITIVITY.
34	INT HEAD Z ACCEL (G)	ENTRAN EGA-125F-100D	93F93F11-P13	8-Jan-01	1.9711 mv/g	21-May-01	1.9541 mv/g	-.9	10 V	100	50.7 G	USED FOR ADAM TESTS 4335 to 4354. USE NEGATIVE SENSITIVITY.
34	INT HEAD Z ACCEL (G)	ENTRAN EGV3-F-250	97C97C27 TB06	8-Jan-01	.9177 mv/g	22-May-01	.9078 mv/g	-1.1	10 V	100	109 G	USED FOR LOIS TESTS 4319 to 4334.
35	INT HEAD RY ANG ACCEL (RAD/SEC2)	ENDEVCO 7302BM2	10006	9-Jan-01	48.51 uv/rad/sec2	22-May-01	48.93 UV/rad/sec2	.9	10 V	50	4122.9 RAD/SEC2	USED FOR ADAM TESTS 4335 to 4354. USE NEGATIVE SENSITIVITY.
35	INT HEAD RY ANG ACCEL (RAD/SEC2)	ENDEVCO 7302BM2	10010	9-Jan-01	-45.10 uv/rad/sec2	NA	NA	NA	10 V	50	4434.6 RAD/SEC2	USED FOR LOIS TESTS 4319 to 4334. USE NEGATIVE SENSITIVITY. Data appeared good but sensor would not calibrate.

36	INT CHEST X ACCEL (G)	ENTRAN EGA-125F-100D	93F93F11-P17	8-Jan-01	1.9259 mv/g	21-May-01	1.8935 mv/g	-1.1	10 V	100	51.9	USED FOR ADAM TESTS 4335 to 4354. USE NEGATIVE SENSITIVITY.
36	INT CHEST X ACCEL (G)	ENTRAN EGV3-F-250	97F97F10 TP06	8-Jan-01	.8724 mv/g	22-May-01	.8908 mv/g	2.1	10 V	100	114.6 G	USED FOR LOIS TESTS 4319 to 4334.
37	INT CHEST Y ACCEL (G)	ENTRAN EGA-125F-100D	93F93F11-P04	8-Jan-01	-1.9146 mv/g	22-May-01	1.9131 mv/g	-.1	10 V	100	52.2 G	USED FOR ADAM TESTS 4335 to 4354. USE NEGATIVE SENSITIVITY.
37	INT CHEST Y ACCEL (G)	ENTRAN EGV3-F-250	97F97F10 TP06	8-Jan-01	-.8809 mv/g	22-May-01	.8837 mv/g	.3	10 V	100	113.5 G	USED FOR LOIS TESTS 4319 to 4334. USE NEGATIVE SENSITIVITY.
38	INT CHEST Z ACCEL (G)	ENTRAN EGA-125F-100D	96F96F04-E06	8-Jan-01	1.6643 mv/g	21-May-01	1.6516 mv/g	-.8	10 V	100	60.1 G	USED FOR ADAM TESTS 4335 to 4354.
38	INT CHEST Z ACCEL (G)	ENTRAN EGV3-F-250	97F97F10 TP06	8-Jan-01	.912 mv/g	22-May-01	.9064 mv/g	-.6	10 V	100	109.6 G	USED FOR LOIS TESTS 4319 to 4334.
39	INT CHEST Ry ANG ACCEL (RAD/SEC2)	ENDEVCO 7302B	F02N	8-Jan-01	3.74 uv/rad/sec2	22-May-01	3.10 uv/rad/sec2	-20.1	10 V	500	5347.6 RAD/SEC2	USED FOR ADAM TESTS 4335 to 4354.
39	INT CHEST Ry ANG ACCEL (RAD/SEC2)	ENDEVCO 7302B	F96M	8-Jan-01	-3.36 uv/rad/sec2	22-May-01	3.39 uv/rad/sec2	.9	10 V	500	5952.4 RAD/SEC2	USED FOR LOIS TESTS 4319 to 4334. USE NEGATIVE SENSITIVITY.
41	INT LUMBAR Y FORCE (LB)	DENTON 1914A	337	2-May-01	-6.35 uv/lb	2-Jul-01	6.33 uv/lb	-.3	10 V	1000	1574.8 LB	USED FOR ADAM TESTS 4335 to 4354. USE NEGATIVE SENSITIVITY.
41	INT LUMBAR Y FORCE (LB)	DENTON 1914A	296	4-May-01	6.63 uv/lb	25-Jun-01	6.64 uv/lb	.2	10 V	1000	1508.3 LB	USED FOR LOIS TESTS 4319 4334.
42	INT LUMBAR Z FORCE (LB)	DENTON 1914A	337	2-May-01	-2.71 uv/lb	2-Jul-01	2.71 uv/lb	0	10 V	1000	3690 LB	USED FOR ADAM TESTS 4335 to 4354. USE NEGATIVE SENSITIVITY.
42	INT LUMBAR Z FORCE (LB)	DENTON 1914A	296	4-May-01	-2.45 uv/lb	25-Jun-01	2.45 uv/lb	0	10 V	1000	4081.6 LB	USED FOR LOIS TESTS 4319 to 4334. USE NEGATIVE SENSITIVITY.
43	INT LUMBAR Mx TORQUE (IN-LB)	DENTON 1914A	337	2-May-01	5.20 uv/in-lb	2-Jul-01	5.10 uv/lb	-2	10 V	1000	1923.1 IN-LB	USED FOR ADAM TESTS 4335 to 4354.
43	INT LUMBAR Mx TORQUE (IN-LB)	DENTON 1914A	296	4-May-01	5.23 uv/in-lb	25-Jun-01	5.11 uv/lb	-2.3	10 V	1000	1912 IN-LB	USED FOR LOIS TESTS 4319 to 4334.
44	INT LUMBAR My TORQUE (IN-LB)	DENTON 1914A	337	2-May-01	5.14 uv/in-lb	2-Jul-01	5.12 uv/lb	-.4	10 V	1000	1945.5 IN-LB	USED FOR ADAM TESTS 4335 to 4354.

44	INT LUMBAR My TORQUE (IN-LB)	DENTON 1914A	296	4-May-01	5.16 uv/in-lb	25-Jun-01	5.14 uv/lb	-.4	10 V	1000	1938 IN-LB	USED FOR LOIS TESTS 4319 4334.
45	INT LUMBAR Mz TORQUE (IN-LB)	DENTON 1914A	337	2-May-01	8.70 uv/in-LB	2-Jul-01	8.69 uv/lb	-.1	10 V	500	2298.9 IN-LB	USED FOR ADAM TESTS 4335 to 4354.
45	INT LUMBAR Mz TORQUE (IN-LB)	DENTON 1914A	296	4-May-01	8.75 uv/in-lb	25-Jun-01	8.74 uv/lb	-.1	10 V	500	2285.7 IN-LB	USED FOR LOIS TESTS 4319 to 4334.
46	LUMBAR Z ACCEL (G)	ENTRAN EGA-125F-100D	18W6W-V24-24	8-Jan-01	-1.6063 mv/g	22-May-01	1.5879 mv/g	-1.2	10 V	50	124.5 G	USED FOR ADAM TESTS 4335 to 4354. USE NEGATIVE SENSITIVITY.
46	LUMBAR Z ACCEL (G)	ENTRAN EGV3-F-250	96L96L30 TS01 X	9-Mar-01	.9629 mv/g	22-May-01	.9771 mv/g	1.5	10 V	50	207.7 G	USED FOR LOIS TESTS 4319 to 4334.
47	INT LUMBAR X FORCE (LB)	DENTON 1914A	337	2-May-01	6.37 uv/lb	2-Jul-01	6.37 uv/lb	0	10 V	1000	1569.9 LB	USED FOR ADAM TESTS 4335 to 4354.
47	INT LUMBAR X FORCE (LB)	DENTON 1914A	296	4-May-01	6.61 uv/lb	25-Jun-01	6.61 uv/lb	0	10 V	1000	1512.9 LB	USED FOR LOIS TESTS 4319 to 4334.