AIRCRAFT SEAT CUSHION PERFORMANCE EVALUATION AND REPLACEMENT IMPLEMENTATION

A. ADAMS, H. M. LANKARANI
National Institute for Aviation Research
Wichita State University
Wichita, KS 67260-0093, U.S.A.

Dr. Nick M. SAFAI
Chair of Engineering Department
Salt Lake Community College
SLC,UT 84123, U.S.A.

The seat cushion on an aircraft seat acts as a spring/damper that is located in the primary load path between the seat occupant and the seat structure. The seat cushion is considered a primary component in the seat system. It must be included and certified as part of the seat system during the seat dynamic test program. It has been demonstrated that the seat cushion's physical properties, if improperly chosen, can amplify the lumbar-column pelvic load of the seated occupant during a vertical impact condition. The lumbar load response of an occupant on a seat is dependent on the combined stroking distance of the seat structure, pan and cushion. The stroking distance reduces the velocity build-up experienced by the occupant prior to bottoming-out, and is desirable in limiting the magnitude of the lumbar load. In the absence of a stroking seat structure, the seat pan and cushion combination determines the outcome of the spine load response. The behavior of the seat cushion depends primarily on the property of the foam materials, which in-turn, is characterized by the compressive load versus deflection response of the material. Seat cushions that are fabricated from different foam materials will have the same influence on the spine load if the load-deflection characteristics of the foams are similar. Component tests will be performed to determine an equivalent foam build-up substitution for repeating time consuming and expensive full-scale test method.

Introduction

The purpose of this paper was to evaluate the dynamic performance of the typical aircraft seat cushions utilized in airline industry. Method described here defines the test procedures in order to replace the seat cushion foam build-up on a dynamically certified seat. The general test methodology is based on finding material equivalent properties, where the previously certified foam build-up and the new foam build-up have similar material behavior. In order to ensure that the replacement foam build-up is equivalent to the current passenger seat build-up, their performance under dynamic loading must be closely matched.

This procedure is aimed at replacing the full-scale testing of the new setup. At later stages, full-scale sled tests will be conducted to validate a comparable foam build-up substitute. Figure 1 illustrates a flowchart of a methodology to authenticate the replacement of the seat cushion on a dynamically certified seat without conducting the full-scale tests. The material equivalency is the main objective of this methodology [8]. The new seat cushion should possess the same load deflection as of the current certified cushions [5].

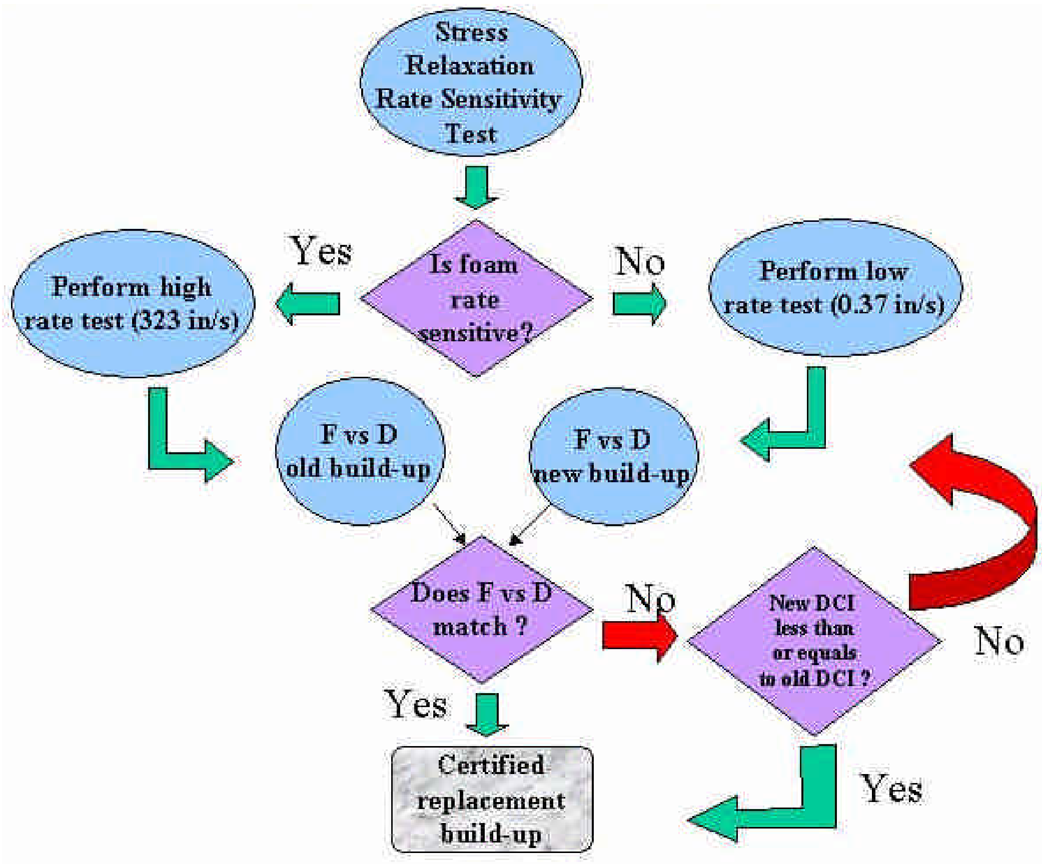
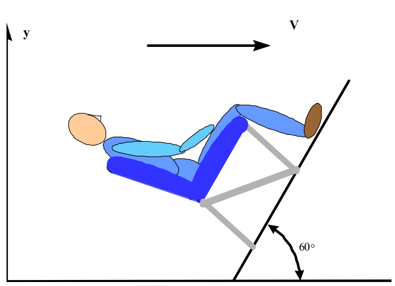
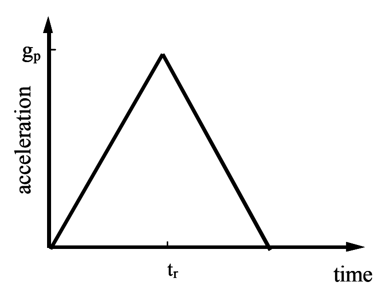


Figure1. Methodology flowchart [5]

1. Overview

The seat dynamic performance standards found in CFR 14, FARs Part 23 (General Aviation), 25 (Transports) , and 27(Rotorcraft) require conduct of two dynamic seat tests and an evaluation of associated pass/fail criteria for aircraft seat certification [1-3]. One of those tests is a combined vertical/longitudinal impact condition that measures among others the lumbar-column pelvic load in the Part 572 Subpart B Hybrid II anthropomorphic test dummy (ATD) [4]. The maximum measured lumbar-column pelvic compressive load in the ATD must not exceed the 1500 pounds pass/fail criterion. This test,
illustrated in Figure 2 and described in Table 1, is intended to evaluate the means by which the lumbar load produced by the combined vertical/longitudinal environment, typical of an aircraft crash event, is reduced.





(a) Test I condition (b) Test pulse shape

Figure 2. Federal Aviation Regulation Test-I configuration

		Part 23		Part 25	Part 27
		Pilot	Passenger		
Velocity Change	ft/s	31	31	35	30
g_p	g's	19	15	14	30
t_r	Sec	0.05	0.06	0.08	0.031

Table 1. Test 1 dynamic test requirement (combined vertical/longitudinal test)

The seat cushion on a seat acts as a spring/damper that is located in the primary load path between the seat occupant and the seat structure. The seat cushion is considered a primary component in the seat system. It must be included and certified as part of the seat system during the seat dynamic test program. It has been demonstrated that the seat cushion's physical properties, if improperly chosen, can amplify the lumbar-column pelvic load of the seated occupant during a vertical impact condition. Any replacement of the seat cushion with another with different physical properties is considered a major change of the seat system and it requires recertification of the seat system. A full-scale seat dynamic test, such as the one shown in Figure 3 is currently required to recertify the new seat cushion and seat system.

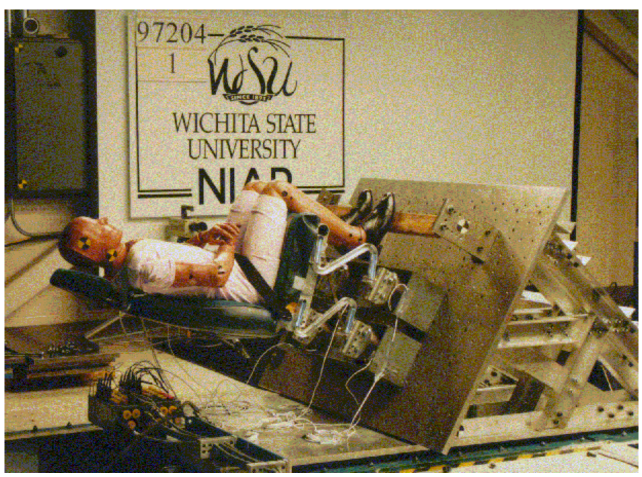


Figure 3. Full-scale sled test for certification of seats

The seat manufacturers and the aircraft owners and operators have long sought a procedure that could be used to certify a seat cushion replacement without conduct of a full-scale seat dynamic test. Seat cushions deteriorate in service and need to be replaced. Often the original cushion foam material is no longer available. Seat cushion replacement is also driven by comfort considerations. Desirable materials for comfort are often inefficient for lumbar load attenuation, while effective materials for lumbar load attenuation are often unacceptable from a comfort standpoint. Suitable designs usually rely on trade-off made between the two. Different foam materials are at times proposed as substitutes for the materials used in original seat cushion construction. There is no accepted procedure, short of full-scale seat dynamic tests, that could be used to assess these typical scenarios.

There have been several research programs initiated to develop a simple seat cushion replacement procedure. Most are directed toward the development of a subcomponent test that could evaluate the seat cushion physical properties that affect the lumbar-column pelvic load. The Wichita State University (WSU) has previously conducted research with the FAATC directed towards the identification of the seat cushion physical properties that affect the lumbar-column load. A methodology was used in this research program, shown in Figure 4, that utilized component drop tests of the energy absorbing foam cushions and the design was validated by conducting a full-scale dynamic seat test under Test-1 conditions. Issues including open and close foams cell as well as rate sensitivity were addressed in that program; however, that program stopped short of developing a procedure that could be used to certify an aircraft seat cushion replacement.

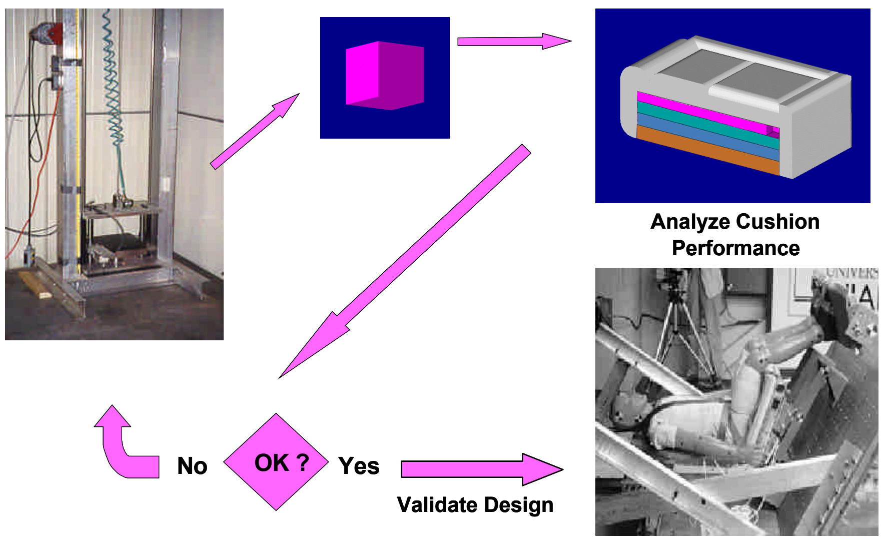


Figure 4. Methodology used in the testing of seat cushions

NASA (National Aeronautic and Space administration) is conducting research directed toward the identification of the seat cushion physical properties that affect the lumbar-column load. Hundreds of dynamic tests of seat cushion foam materials have been conducted to date; however that program has also not yet produced a procedure to certify an aircraft seat cushion replacement [9].

The SAE SEAT Committee has a subcommittee that is also attempting to define a procedure that could be used to certify an aircraft seat cushion replacement. However the subcommittee cannot conduct the dynamic tests of seats or seat cushion materials that are needed to establish the database for the FAA. The Advanced General Aviation Transportation Experiments Program (AGATE) group presented data at their July meeting, the data that supports seat cushion replacement with a well-defined, simple subcomponent test. The AGATE procedure appears to have merit and the NRS has asked for additional full-scale seat tests to be conducted, such that the AGATE procedure can be further validated.

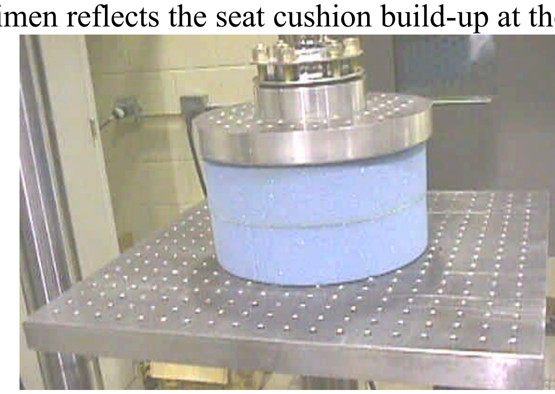
2. Test methodology

The first step in this method is to clarify whether the old foam build-up and new foam build-up are rate sensitive. One method to accomplish this is by performing the "load relaxation test". Once the rate sensitivity is determined for the two types of high and low rate-sensitive foams, the load-deflection behavior of the foams will be obtained. In either case, material equivalency is established if the final load-deflection curves for the new foam and one from the old foam are similar. The test method described above, is a load relaxation test that is used to quantify the rate sensitivity of foam materials. Foam specimens shown in Table 2 are representing the old cushion foam build-up. Once the new foams with unknown properties have been acquired, the same procedure described above will be performed to determine the rate sensitivity of new cushions build-up. The load versus time response of each foam specimen will be recorded and compared to verify its rate sensitivity.

Specimen	Foam Current Build-up Description	Test Specimen Part Number	Foam Thickness (Inches)	Rate (in/s)
Confor-Green	Poly foam build-up	1	4.0	3.7
Confor-Blue	Poly foam build-up	2	4.0	3.7
Confor-Pink	Poly foam build-up	3	4.0	3.7
Confor-Yellow	Poly foam build-up	4	4.0	3.7
DAX-20	DAX foam build-up	5	4.0	3.7
DAX-47	DAX foam build-up	6	4.0	3.7
DAX-70	DAX foam build-up	7	4.0	3.7
DAX-90	DAX foam build-up	8	4.0	3.7

Table 2. Load relaxation test matrix

A new foam build-up will be developed and the load-deflection test will be repeated until a final build-up pattern is obtained. The test specimens consist of flexible open-celled foam. Each specimen is cylindrically shaped and has a diameter of 7.50 ± 0.1 inches, shown in Figure 5. The specimen reflects the seat cushion build-up at the bottom-reference point.



(a) Confor™ Foam (b) DAX Foam

Figure 5. Test article

2. Test setup

The test setup is similar for the load relaxation test and the load-deflection test. Each foam specimen is placed on a perforated rigid flat platform to allow for unrestricted flow of air during the loading and unloading process. A 50 in^2 round indentor is used to apply the load to the center of the foam specimen. The design of the rigid platform and indentor are specified in *ASTM D3574-95.* Figure 6 shows a schematic of the test fixture and setup. It also illustrates a previously certified (current foam build-up), commonly used by aircraft companies.

Figure 6. Test apparatus

A load cell and displacement transducer will be used to measure the force applied to the foam and the corresponding displacement. The force and displacement data will be recorded by means of a data acquisition system, as shown in Figure 7.

Figure 7. Data acquisition System

3. Load relaxation test methodology

The load relaxation test is performed on an MTS machine. A 50 in^2 indentor is attached to the crosshead and is used to compress the foam. The indentor is lowered on to the specimen at a specified rate to a desired extension level, at which point the MTS machine crosshead is held at this position for a period of time to allow for the relaxation to occur.

4. Test Procedures

All test specimens are to be conditioned undistorted for 12 hours at 50 ± 5% relative humidity and at temperature of 73.4 ± 2^0 Fahrenheit prior to test. Foam specimen were then selected from Table 1 and placed on the rigid test platform. The 50 in^2 indentor was then lowered and hold directly over the center and in contact with the foam specimen. Feedback load should read 0 pounds at this time. The area to be tested was preflexed by lowering the indentor twice to a total of 95% of full-part thickness at a rate of .372 in/s. Specimen was allowed to rest 3 ± 1 min after preflexing. Data acquisition was performed and sampled at 2 Hz. The sample was indented at the loading rate of 3.7 in/s until 95% compression is obtained. The indentor was then held in this position for 180 seconds. The indentor was then unloaded and data acquisition was terminated. Tested specimen was replaced by the next specimen foam from Table 2 and the procedure was repeated. Figure 8 depicts the test rate-sensitivity results for Dax and Confor foams [6], from Table 2. Figure 9 also shows the varieties of Confor™ [7] ,cushions. It is apparent that there is a significant difference between the profile of initial stiffness and the maximum deflection change for two types of high and low rate-sensitive cushions of Confor™ and DAX foams.

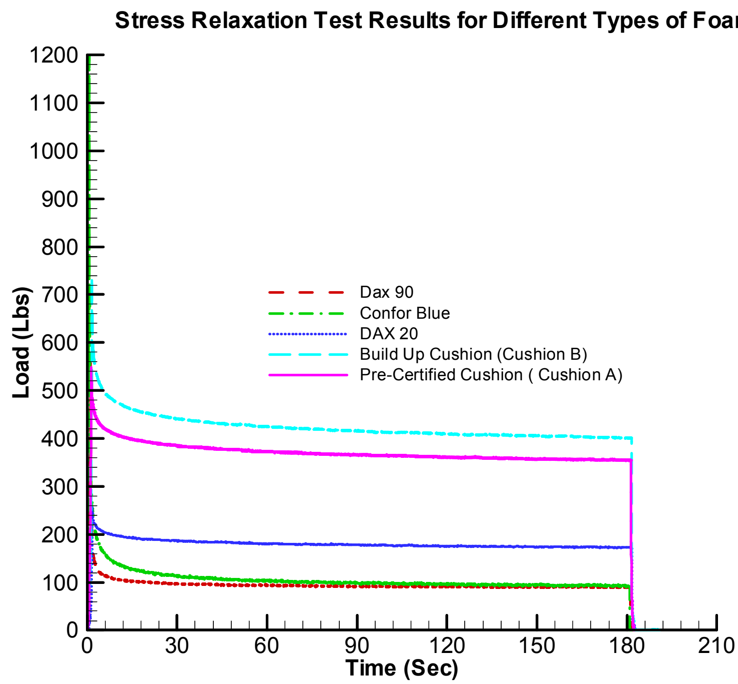


Figure 8. Stress relaxation test

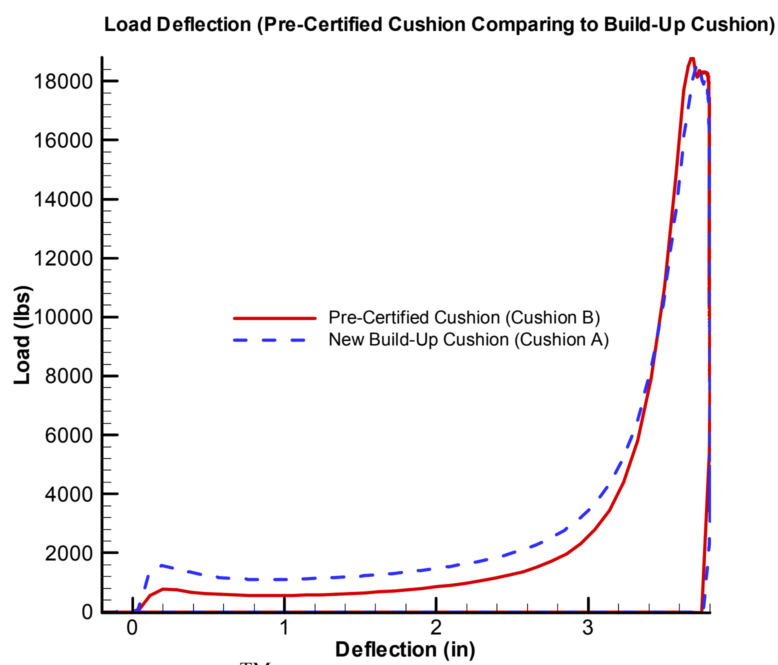


Figure 9. Confor TM foams results (New Cushion Build-Up

5. Dynamic Full Scale sled testing

Full-scale dynamic sled Dynamic tests have been performed at the NIAR (National Institute for Aviation Research) crash lab. Totals of four tests were conducted based on FAR 23 Type-I configuration, two of which were performed without foam cushions and two with. The aim of these tests was to study the lumbar load experienced by the Hybrid II ATD when seated on a

rigid iron seat compared with seat fitted with soft types foam cushion. The tests are helping to study the variation in data between two tests conducted under similar conditions.
FAR 23 Test I Configuration require the dummy to be placed at an angle of 60-degree with respect to the ground. The sled test is conducted with 15G acceleration pulse (FAR 23). The maximum measured lumbar-column pelvic compressive load in the ATD must not exceed the 1500 pounds pass/fail criterion. Test condition is illustrated in Figure 2.
In part 23.562 FAA (Federal Aviation Administration) Type I crash test, the plane impact the ground at the 30-degree pitch down attitude, shown in figure 10. When investigating the effect of the crash acceleration on the occupant and seat, the acceleration pulse must be transformed in to the aircraft coordinate system. FAR 23 is intended to evaluate the means by which the lumbar load produced by the combined vertical/longitudinal environment, typical of an aircraft crash event, is reduced.

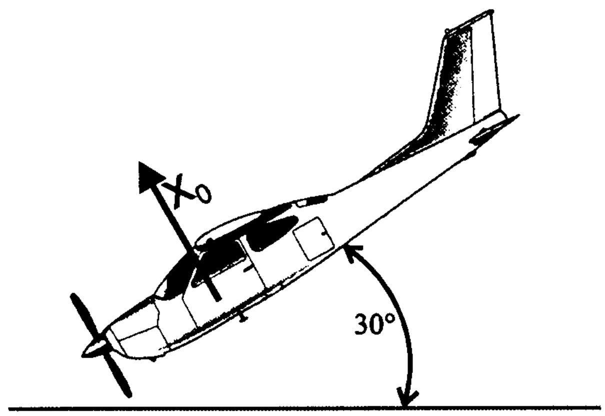


Figure 10. Assumed Geometry for FAA Part 23 Type I test Conditions

The fist two full-scale dynamic sled tests were conducted without use of any seat cushion in order to evaluate the lumbar load exerted on the passenger without any energy absorbing material.
To ensure a complete lack of space between the ATD and the seat, a 1G-load condition (one time force of gravitation acceleration), was imposed on the test article. This was made possible by positioning the ATD dummy down on the rigid seat at 0° angle horizontal and let the ATD set for a period of 20 minutes in that position in order to comply with FAR 23 1G regulation. This is to ensure there would be no distance between the seat surface and the occupant. The seat belt was then fastened on appropriated position anchoring ATD with a 2-point polyester seat belt restrain system. The seat was then mounted on 60° positions prescribed by FAR 23 as shown in figure 2(a), before test was conducted for 15G condition. Figure 11 shows the full sled test # 001144-001 performed at NIAR for none seat cushion condition.

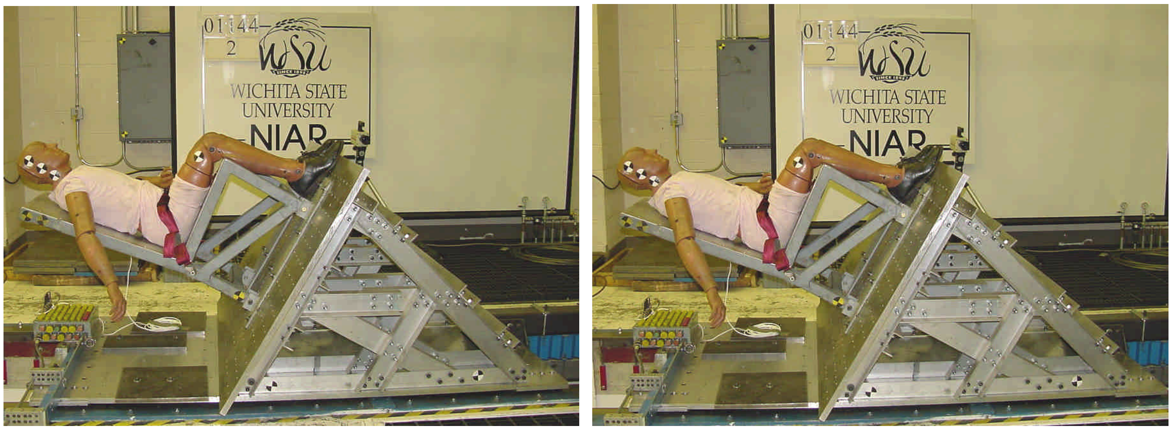


Figure 11. NIAR dynamic full scale sled test with the rigid seat

Figure 11 above shows the NIAR dynamic sled acceleration pulse for 15.6g for AGATE type aircraft passengers seat prescribe in FAR 23.562 (2b) test condition for lumbar-column pelvic loads. Full-scale dynamic sled test was conducted for the third subgroup condition in order to evaluate lumbar-column pelvic loads at the highest load level. Figure 12 shows the ATD Lumbar Load on the none-cushioned rigid seat at the 15.6g pulse acceleration.

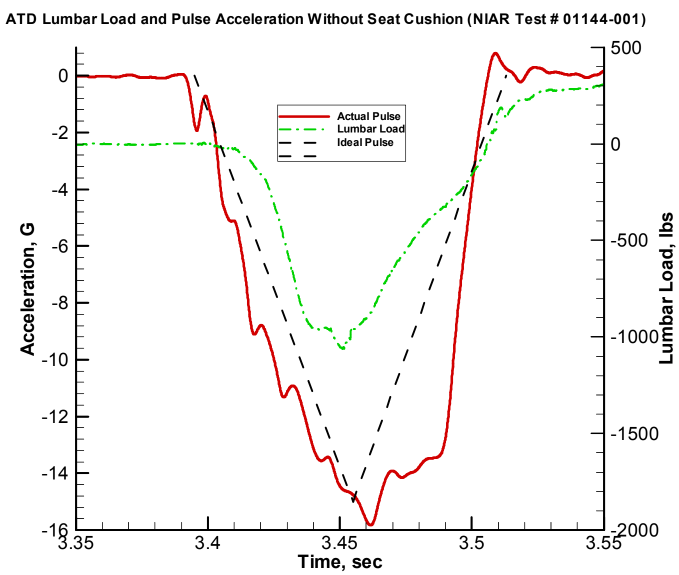


Figure 12. Sled acceleration pulse and the ATD Lumbar Load on the none-cushioned rigid seat

The lumbar load for this condition was recorded at 1,062.54 lbs; well bellow the pass-fail FAA limit lumbar load of 1500 pounds. Cessna Aircraft Company has provided us with a variety texture of seat cushion foams and several test specimens. The cushions appear to be from wide range of High Rate-Sensitive to Low Rate-Sensitive foam materials from different manufacturers. The provided cushions are intended for use in full sled tests at NIAR Crash Dynamic Lab as well as MTS Quasi-Static Test machine at structures lab at NIAR. The test results from the MTS static test will be validated with the resulted tests acquired from Full Scale

Dynamic Sled tests. Figure 13 below is shown the full-scale sled test conducted with a 2.5-inch thick soft foam cushion. The cushion appeared to be a Low rate-sensitive HR 30 Foam type.

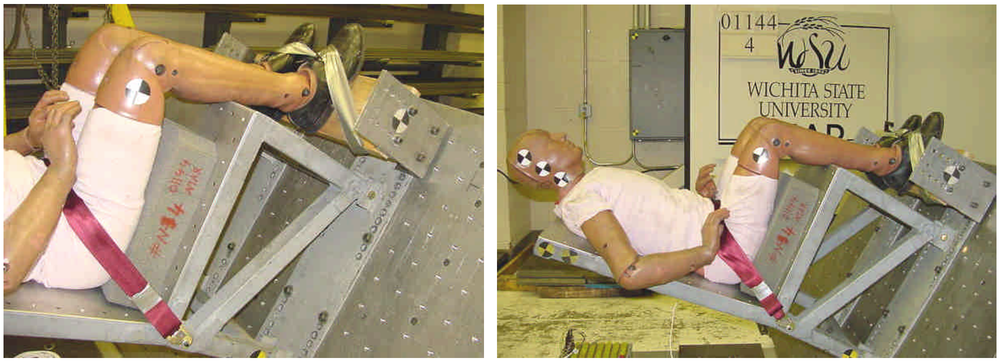


Figure 13 NIAR dynamic full-scale sled test with seat cushion

The second set of test was conducted with a soft foam cushion. As the result of a 15G acceleration pulse, the ATD was mounted on the cushioned seat and test was performed. The ATD Lumbar Load on the test sled with the cushion seat that resulted in much higher lumbar load shown in the figure 14. The results from the two test condition of cushioned and none cushion seat are showing the clear evidence of the increase in lumbar load when soft cushion was used. This phenomenon is due to the ATD position phase shift.

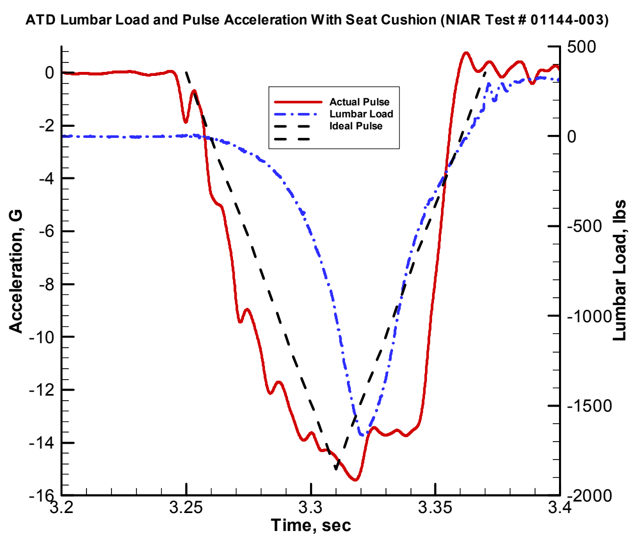


Figure 14. Sled acceleration pulse and the ATD Lumbar Load on the cushioned seat

As predicted, the phase shift has caused the increase in the ATD lumbar load. The NIAR Dynamic test #01144-003 resulted in the high fatal lumbar load of 1,668.21 lbs. The results showing the clear evidence of the failing lumbar load test. This was due to utilizing a low-density soft foam cushion type. These premier role of these types of cushion are clearly the passenger comfort but do not possess any energy absorbing characteristic and therefore, the lack of its ability to absorb the impact load is clearly a higher cause for increase in the passenger spinal injuries and in some cases, fatalities. Generally the soft cushions exhibit a very low dynamic fatigue behavior which results to a poor performance of cushion. Summaries of Dynamic sled test results are depicted in Table 3.

Dynamic Sled Test	Test Condition	Cushion type	Sled Acceleration peak (g's)	Rise Time (ms)	Total Velocity Change (fps)	Velocity Change during Rise time (fps)	Lumbar Load (lbs)
Test 1	Without cushion	N/A	15.6	61.9	36.1	17.7	1,062.54
Test 2	Without cushion	N/A	16.2	61.7	35.8	17.8	1,166.35
Test 3	With cushion	Soft	15.2	64	36.2	18.1	1,668.21
Test 4	With cushion	Soft	15	54.5	36.2	18.5	1,987.59

Table 3. NIAR Dynamic Sled Test results

6. Dynamic Compression Index (DCI)

The next set of full-scale dynamic sled tests have been performed at the NIAR Impact Dynamic laboratory. Tests were conducted in FAR 23 Type-I configuration, two of which were performed without foam cushions and the rest of tests were conducted with varieties of DAX type foams. The emphasis of this month testing was laid primarily on calibration of the full-scale Dynamic test apparatus. The dynamic test configuration includes two identical rigid Iron seats and a pair of Hybrid II ATD's with lumbar load cells attached as observed in figures15 and 16. The purpose of these tests is to study the variation in data between two tests conducted under similar conditions, and tests with process for seat cushion data collection will then followed.

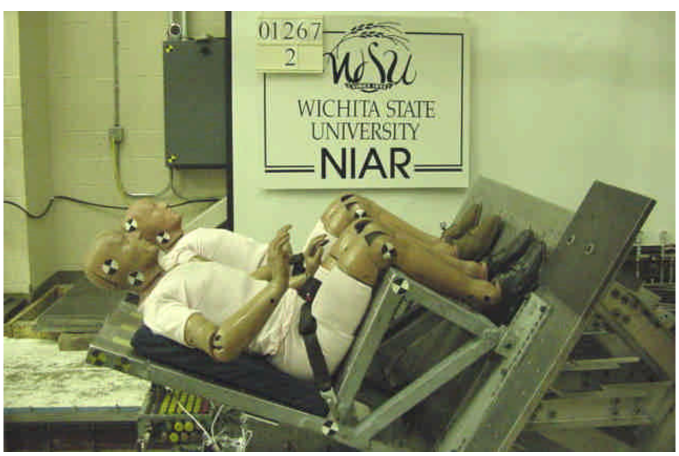


Figure 15. Pair of hybrid ii ATD's seated on two iron seats side by side

Total of four tests with the iron seats (no-foam) were conducted in order to ensure the test device accuracy. Once the accuracy of the device was established, the data acquisition of varieties of the cushions has begin with DAX foams and results were reconfirmed.

Figure 16. Pair of hybrid II ATD's with DAX foam

In order to evaluate the performance of seat cushion and lay-ups, a test matrix was developed as shown in Table 4. The lumbar loads are normalized to 15G,scale.

Foam Types	Color	Thickness (inches)	Dynamic Compression Index(3.7 &.37 in/sec)		MTS Quasi-Static Load - Deflection Test (0.37 & 3.7 in/sec)	Number of Sled Tests	Full Scale Sled test #	Sled Test Acceleration (G's)	Lumbar Load (lbs)	Normalized Lumbar Load (lbs)
No Foam / Bare Iron seat			0	0		2	01267 - 001	15.1	1170.4	**1163**
								15.1	1110.4	**1103**
							01267 - 002	15.5	1306.9	**1265**
								15.5	1342.8	**1299**
DAX 20	Blue	6"	5.3	5.3	X					
DAX 26	Dark Pink	3"	2.7	2.7	X					
		4"	3.7	3.7	X	2	01267 - 007	15.1	1825.8	**1814**
								15.1	1764.1	**1752**
							01267 - 008	14.5	1998.9	**2068**
								14.5	1997.4	**2066**
		6"				2	01267 - 005	15.7	2227.7	**2128**
								15.7	2103.4	**2010**
							01267 - 006	15.2	1985.9	**1960**
								15.2	1947.9	**1922**
		10"				2	01267 - 009	16.5	2248.4	**2044**
								16.5	2229.4	**2027**
							01267 - 010	16.7	2065.9	**1856**
								16.7	2156.4	**1937**
DAX 47	Green	6"	5.5	5.4	X					
DAX 55	Grey	4"				2	01267 - 011	15.5	1996.3	**1932**
								15.5	1896.0	**1835**
							01267 - 012	16.4	2418.4	**2212**
								16.4	2300.1	**2104**
DAX 90	Brown	2"	3.5	5.4	X					
		4"	1.8	3.4	X					
		8"	5.9	5.9	X	2	01267 - 003	17.0	1604.5	**1416**
								17.0	1588.2	**1401**
							01267 - 004	16.2	1586.2	**1469**
								16.2	1400.2	**1296**

Table 4. Seat cushion replacement program matrix

The combined above results obtained from both Quasi-static and dynamic tests will enable the final desired result of spine load versus the dynamic compression index, shown in Figure 17.
The final DCI result is comprised of the dynamic full-scale sled and quasi-static cushion tests, resulted from MTS test stands. The deviation and its effect on the spine load can be determine using the DCI chart shown in Figure 17. It is notable that a smaller DCI results in lower spine load. If the deviation in DCI of the new foam build-up is equivalent to or smaller than the old build-up, then the new foam build-up is certified [5]. However, if the DCI value is larger, a new build-up is required and the process is repeated until an equivalent load-deflection response and DCI value is obtained.

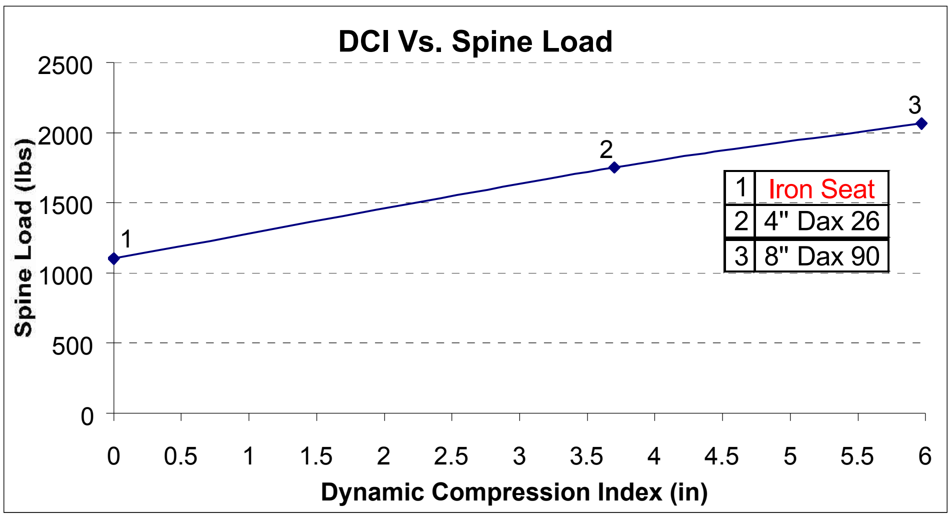


Figure 17. Dynamic compression index (DCI) versus spine load

7. Conclusion

The seat cushion is considered a primary component in the seat system. It must be included and certified as part of the seat system during the seat dynamic test program. It has been demonstrated that the seat cushion's physical properties, if improperly chosen, can amplify the lumbar-column pelvic load of the seated occupant during a vertical impact condition. Any replacement of the seat cushion with another with different physical properties is considered a major change of the seat system and it requires rectification of the seat system. The lumbar load response of an occupant on a seat is dependent on the combined stroking distance of the seat structure, pan and cushion. The stroking distance reduces the velocity build-up experienced by the occupant prior to bottoming-out, and is desirable in limiting the magnitude of the lumbar load. In the absence of a stroking seat structure, the seat pan and cushion combination determines the outcome of the spine load response. The behavior of the seat cushion depends primarily on the property of the foam materials, which in-turn, is characterized by the compressive load versus deflection response of the material. Relative closed results between the cushions are notable. For a given acceleration pulses, each cushion has performed well. Although the Low rate-sensitive type cushions (soft, conformable foam cushions) appear quite comfortable from the passenger point of view, the relative higher lumbar loads of these types of cushions in comparison to a firmer cushions which appear uncomfortable and hard, reconfirm that the thinner and firmer cushions almost always results in lower lumbar load and therefore creating a safer environment for the airline passengers. This issue must be reiterated with the public that what is comfortable is not necessarily safe for the passenger's well being at time of aircraft hard landing and unforeseen crash events.

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9. Biography

1. ADAMS, A., Senior Aerospace Research scientist at the National Institute for Aviation Research, Wichita, Kansas, U.S.A.
2. LANKARANI, H.M., Professor of Mechanical Engineering at Wichita State University, Bombardier/Learjet fellow, Director of Crashworthiness Research, National Institute for Aviation Research, Wichita, Kansas, U.S.A.
3. SAFAI, N. M., Professor of Mechanical Engineering Department, Chair of Engineering Department, at Salt Lake City College, Salt Lake City, Utah, U.S.A.