

THE OPTIMIZED THREE WEIGHT RANGE, FIVE FORCE LEVEL EA SYSTEM FOR ENERGY ABSORBING CREW SEATS

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ABSTRACT

The addition of small females into the helicopter pilot population has increased appreciably the weight range for which energy absorbing crew seats must provide low probability of spinal injury performance in survivable crashes. The three weight range, five force level (3WR/5FL) energy absorber system is a simple approach to the solution of the problems associated with providing maximum aviator protection against spinal injury even in thirty-degree nose-down survivable crashes for the total pilot population. This paper presents the results of an optimization study performed on the 3WR/5FL energy absorber system. This study indicates that in a 42 feet per second crash the dynamic response index (DRI) can be kept at or below 18.2, the maximum lumbar acceleration will be at least 1.0G below the acceptable level of 20.4G, and the maximum energy absorber stroke can be kept at or below 13.8 inches for small pilots, who will have the seat adjusted up for correct eye position, and at or below 12 inches for average and large pilots. This system is light weight, comparatively low cost, small size, easily maintained, simple in operation, truly reliable and can meet the specification requirements for energy absorber systems.

1. BACKGROUND

The basic concept of the Three Weight Range/Five Force Level (3WR/5FL) Energy Absorber System was described in the paper, "THE MULTI WEIGHT RANGE, MULTI FORCE LEVEL EA SYSTEM"¹ that was presented at the 2004 SAFE Symposium. Because of time limitations no attempt to truly optimize the basic 3WR/5FL-EA system had been made up to that time. Also no serious study of the thirty-degree nose-down aircraft crash event was performed up to that time. Subsequent to that meeting an attempt to optimize the 3WR/5FL-EA system for the baseline crash event as defined in the Simula Safety Systems, Inc. Final Report for Contract No. N62269-92-C-0217 dated 28 November 2000 (TR-97256A)² was undertaken and significant results have been achieved. Before these results will be considered herein some of the data available in this Simula Safety Systems Final Report, TR-97256A, will be discussed.

2. IMPORTANT DATA FROM TR-97256A

The Simula Safety Systems Final Report, TR-97256A, provides important data that must be taken into account in any evaluation of the performance of an energy absorber system in the thirty-degree nose-down aircraft attitude in the baseline crash event. Figure 18 on page 43 of this TR-97256A report provides eight sequential schematic pictures of the large 95th percentile male seat occupant at 20 millisecond

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intervals from time equal zero up to 140 milliseconds for the zero-degree pitch angle crash condition with the variable-profile energy absorber (VPEA) active. Figure 1 in this paper includes the two schematic pictures at time equal zero and at time equal 140 milliseconds of that figure. The seat back in these two schematic pictures is pitched about 13 degrees aft of vertical and the seat pan is pitched up about two degrees from the horizontal. As a result the upward acceleration of the large male seat occupant that the VPEA would produce in this crash condition acts to push the seat occupant's upper torso and lower torso into the seat back and any loads in the torso belts and tie down strap are reduced from their initial values throughout the total 140 millisecond VPEA action time interval for the 95th percentile male seat occupant.

Figure 19 on page 44 of TR-97256A provides eight sequential schematic pictures at 20 millisecond intervals for the 95th percentile male from time zero up to 140 milliseconds for the VPEA in the 30-degree nose-down pitch angle crash condition. Figure 2 in this paper includes the two schematic pictures at time equal 100 milliseconds and at time equal 140 milliseconds of that figure. The seat back angle in this figure is pitched almost 13 degrees aft of the 30-degree nose-down pitch angle (or about 17 degrees forward of vertical) and the seat pan is pitched up about two degrees from the 30-degree nose-down pitch angle (or about 28 degrees downward from the horizontal). With this seat attitude the upward and aft ward acceleration of the large male seat occupant in this crash condition acts to pull the seat occupant's upper torso and lower torso forward away from the seat back. This action results in a major increase of the tension levels in the torso belts and the tie down strap especially at the end of the 140 millisecond VPEA action time. These increased tension levels resulted in a large increase in the 95th percentile male lumbar load above the 2534 pound lumbar tolerance level for the acceptable 20.4G acceleration level. In this Figure 19 it is clear that the energy absorber performance capability should be able to reach the end of its action time in about 100 milliseconds or less for the large 95th percentile male seat occupant if these tie down strap loads are to be kept from increasing the lumbar load above the acceptable 20.4G level. Even though these strap loads are existing at the 100 milliseconds time, their downward component that could act to increase the lumbar load, is appreciably smaller. Thus if the upward acceleration of the lumbar supported seat occupant mass is kept to a reasonable value a lumbar load greater than the 2534 pound lumbar tolerance level for the large 95th percentile male acceptable 20.4G acceleration level will not result.

It is noted that the optimization of the 3WR/5FL EA system was performed with the baseline crash pulse acceleration acting directly in line with the seat occupant's spine. This condition then represents the worst case energy absorber condition of a 13-degree nose-down pitch attitude of the aircraft during the baseline crash event. All other either nose-down or nose-up pitch attitudes of the aircraft during this baseline crash event will have a shorter energy absorber action time and will have a shorter energy absorber stroke than those of this 13-degree nose-down aircraft attitude for any and all seat occupant weights.

3. 3WR/5FL EA SYSTEM DESCRIPTION

The process that was used to set the minimum and maximum seat supported weights in each of the three (low, mid and high) weight ranges will be described in Section 4. The extremely simple means for selecting the energy absorber multi-force

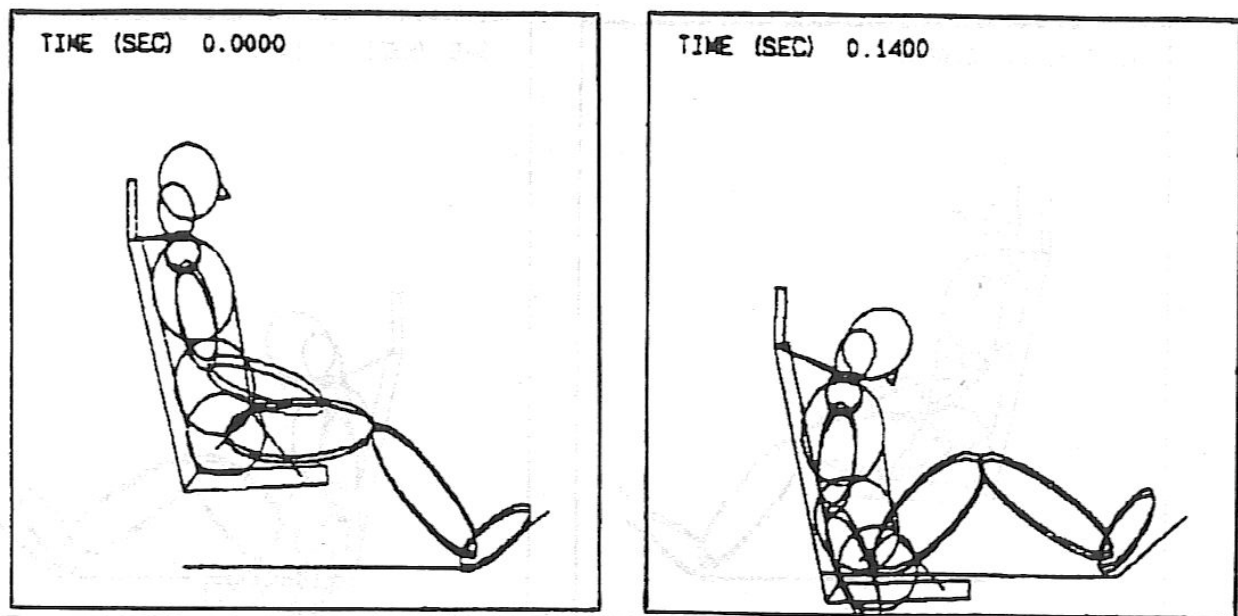


Figure 1. Occupant response to zero-degree pitch angle with variable-profile energy absorber at $t = 0.0$ and 0.14 second.

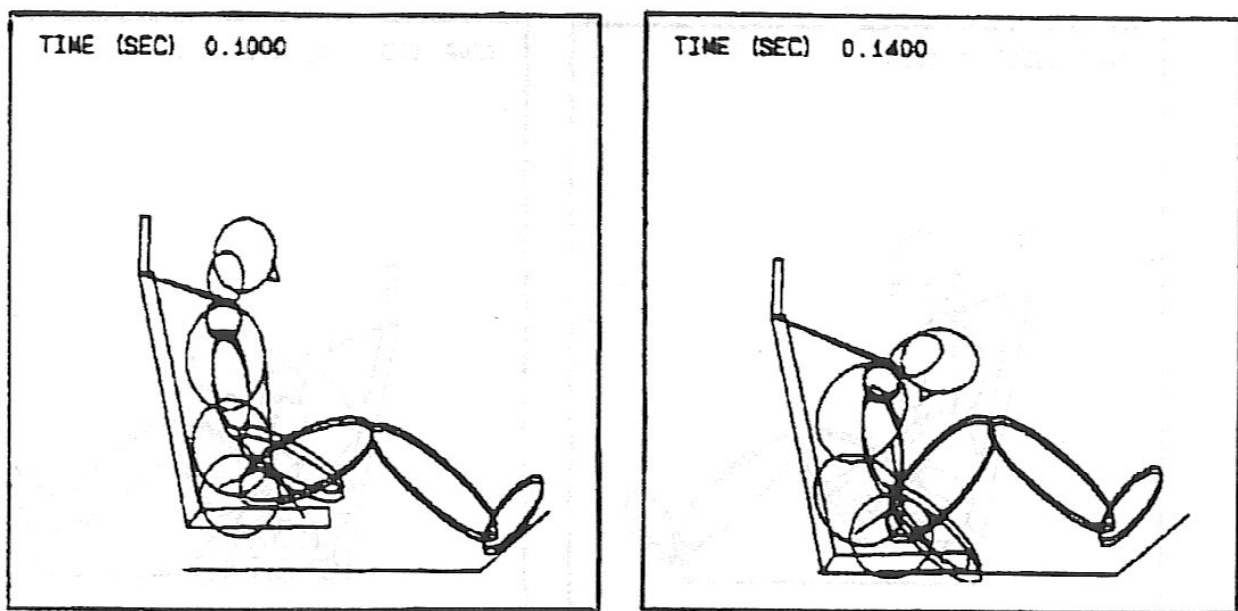


Figure 2. Occupant response to 30-degree nose-down pitch angle with variable profile energy absorber at $t = 0.10$ and 0.14 second.

levels in these three weight ranges will now be described. When the aircraft power is turned on each EA crew seat will have seat supported weight sensing means, which will be capable of determining the weight range the seat occupant is in. If the sensed seat supported weight is below the low to mid weight range crossover value neither the mid weight range solenoid pair nor the high weight range solenoid pair will be operated and only the low weight range left-hand and right-hand energy absorbers will be active in the event of a crash condition. If the sensed seat supported weight is equal to or greater than the low to mid weight range crossover value, and is less than the mid to high weight range crossover value, the mid weight range solenoid pair will be operated and the high weight range solenoid pair will not be operated. Thus both the low weight range and the mid weight range left-hand and right-hand energy absorbers will be active, but the high weight range energy absorbers will not be active in the event of a crash condition. If the sensed seat supported weight is equal to or greater than the mid to high weight range crossover value both the mid weight range solenoid pair and the high weight range solenoid pair will be operated and all three weight range left-hand and right-hand energy absorbers will be active in the event of a crash condition occurring.

The three energy absorber mechanisms that either separately or in combination provide the proper energy absorbing force level versus stroke distance for the three weight ranges will each produce the following force-distance characteristics after a shear pin providing an initial carefully controlled high force level (over about 0.1 inch travel) has been successfully sheared.

- (1) A lower F1 "Notch" force level, about 0.10 to 3.75 inch stroke.
- (2) A higher F2 "1st Hold" force level, about 4.0 to 7.75 inch stroke.
- (3) A higher F3 "2nd Hold" force level, about 8.0 to 10.50 inch stroke.
- (4) A higher F4 "3rd Hold" force level, about 10.75 to 12.20 inch stroke.
- (5) A higher F5 "4th Hold" force level, above 12.45 inch stroke (active in the low weight range only).

As was discussed in the Multi Weight Range, Multi Force Level EA System 2004 SAFE Symposium paper the five energy absorbing force levels acting over the desired distances can be easily and inexpensively obtained using stitch ripping in standard webbing. The different force levels are controlled by the strength of the thread or cord used in the stitching, the number of stitches per inch sewn, and the number of stitching rows provided. Figure 3 includes three graphs of the optimized low, mid, and high weight range energy absorbers with the computed strokes of the stitch ripping energy absorbers for most of the seat supported weights considered in the optimization study of the worst case 13-degree nose-down pitch aircraft attitude in the baseline crash event.

4. 3WR/5FL EA SYSTEM OPTIMIZATION

The primary goal in the 3WR/5FL EA system optimization was to reduce the maximum dynamic response index, DRI, to about 18 for all seat occupants throughout the total pilot population from the small 102.8 pound 5th percentile female (93.1 pounds seat pan supported weight) up to the large 212 pound 95th percentile male (180.5 pounds seat pan supported weight). Along with this DRI reduction to about 18 was the reduction of the maximum lumbar acceleration level below its tolerance level of 20.4G by a margin of at least 1.0G throughout this total pilot population. The reduced DRI and

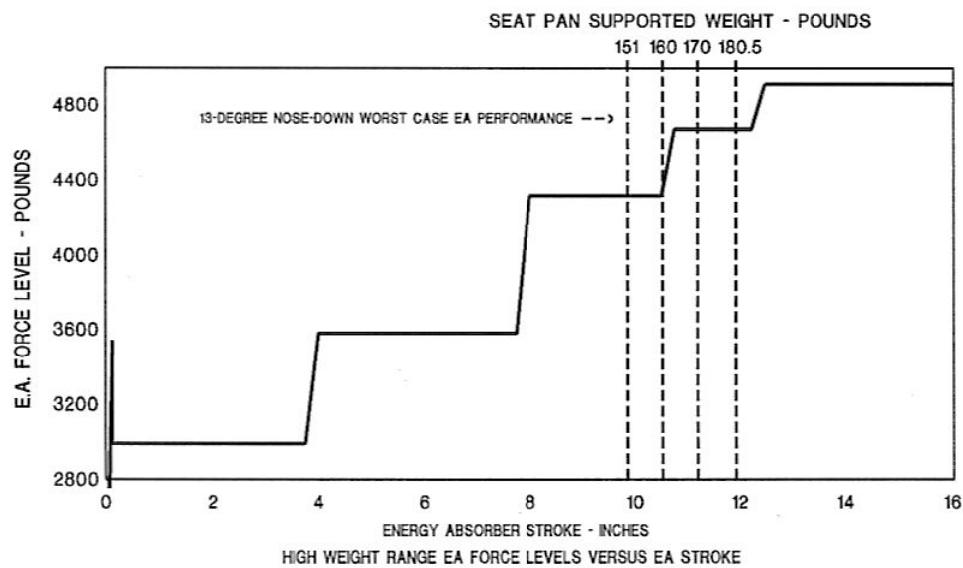
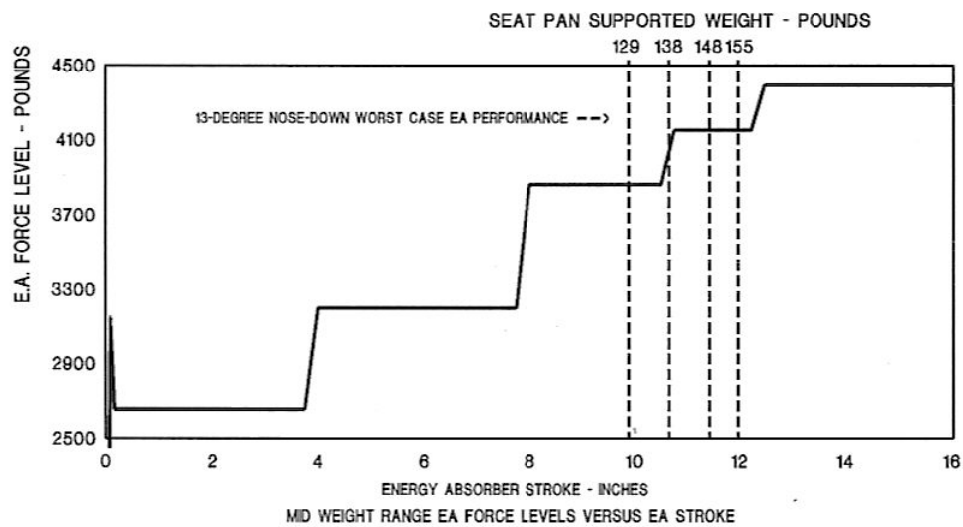
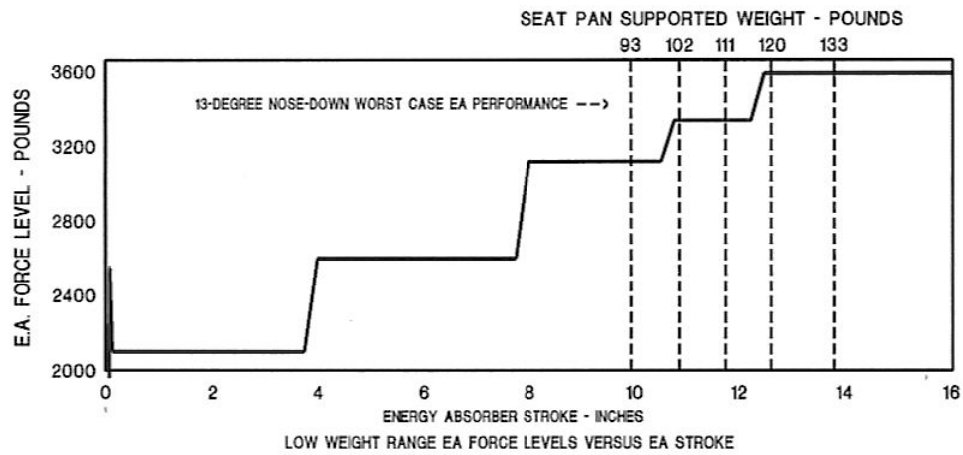


Figure 3. EA force levels for the three weight ranges

lumbar acceleration levels were obtained for the worst case 13-degree nose-down pitch attitude where the 42 feet per second crash velocity vector is directly in line with the spine of the seat occupant and produces the longest energy absorber action time and the largest energy absorber stroke for the seat occupant weight being decelerated. For this optimization effort it was decided that the maximum seat occupant weight in the low weight range would represent a relatively small male or female seat occupant. As a result the seat adjustment in this weight range would never be so low that there would be less than 13.87 inches of seat pan travel before it hits the floor (i.e. setting the maximum energy absorber allowable stroke to 13.87 inches). The maximum allowable stroke in the mid weight range and in the high weight range is maintained at 12 inches as some of these larger seat occupants might have a long enough torso to have the seat adjusted to its full down position.

As noted above the 3WR/5FL EA system was optimized in the 13-degree nose-down pitch attitude of the aircraft in which the baseline 42 feet per second crash event was directly in line with the seat occupant's spine. In this worst case crash attitude the optimized seat occupant low weight range was developed on the basis that the smallest seat pan supported weight of 93.1 pounds (102.8 pounds body weight) would have a DRI as close as possible to 18 (18.2 actual) and the largest possible seat pan supported weight would be that which would have a maximum energy absorber stroke of 13.8 inches. This maximum low weight range seat pan supported weight was found to be 133 pounds (152.6 pounds body weight) which has the longest energy absorber stroke time for this low weight range of 104 milliseconds. This longer than 100 millisecond energy absorber stroke time is considered very acceptable since the torso belts and the tie down strap will not be appreciably loaded by this 133 pound seat pan supported weight seat occupant in this essentially zero forward torso acceleration crash condition.

A crossover weight tolerance of plus/minus two pounds was used to set the nominal low weight range to mid weight range seat pan supported crossover weight as 131 pounds and the minimum seat pan supported weight in the mid weight range as 129 pounds (147.6 pounds nude weight). The maximum seat pan supported weight in this mid weight range was set as that which would have a 12 inch energy absorber stroke and was found to be 155 pounds (180.1 pounds body weight). The maximum DRI in this mid weight range for the 129 pound seat pan supported weight was calculated as 18.1. It is noted that the maximum energy absorber stroke time in this mid weight range for the 155 pound seat pan supported weight was 98 milliseconds.

Again, as was true above, the crossover weight tolerance of plus/minus two pounds was used to set the nominal mid weight range to high weight range seat pan supported crossover weight as 153 pounds and the minimum seat pan supported weight in the high weight range as 151 pounds (175.1 pounds body weight). The maximum seat pan supported weight in this high weight range was set as that which would have a 12 inch energy absorber stroke and was found to be 180.5 pounds (212.0 pounds body weight, which is the large 95th percentile male). The maximum DRI in this high weight range for the 151 pound seat pan supported weight was calculated as 18.0 and the maximum energy absorber stroke time in this high weight range for the 180.5 pound seat pan supported weight was 98 milliseconds.

Table I lists the performance as computed for the optimized 3WR/5FL EA system for eighteen seat pan supported weights (seven in the low weight range, six in the mid weight range and five in the high weight range). The listed data values include the Maximum Upper Occupant Acceleration (for lumbar load), the First Maximum DRI

value, the Second Maximum DRI value, and the EA Stroke Distance. The times at which these four data values occur are also provided.

The data in this table clearly indicates that the performance of the optimized 3WR/5FL EA system, even in this worst case aircraft attitude, meets the specification requirements for energy absorbing crew seats throughout the total aircrew population of the 5th percentile female up to the 95th percentile male. The very important question that still remains is: "Will it also protect the total aircrew population in the 30-degree nose-down aircraft attitude where the VPEA system was found to be deficient?"

Table I. The Optimized 3WR/5FL EA 13° Nose-Down System Performance

WEIGHT RANGE	SEAT PAN SUPPORTED WEIGHT POUNDS	MAX. UPPER OCCUPANT ACCEL/TIME g/MS	FIRST MAXIMUM DRI/TIME g/MS	SECOND MAXIMUM DRI/TIME g/MS	EA STROKE DISTANCE AND TIME INCHES/MS
LOW	93 ¹	19.2/46	18.2/58	18.2/94	9.94/94
	102	18.9/94	17.1/57	18.0/97	10.85/97
	111	18.9/97	16.1/56	18.0/100	11.72/99
	116 ²	18.8/99	15.5/56	17.9/101	12.22/99
	120	19.1/99	15.1/56	18.0/103	12.58/99
	131	19.0/103	14.1/55	18.0/105	13.59/103
	133	18.9/103	14.0/54	18.0/103	13.78/103
MID	129	19.3/45	18.2/56	18.2/94	9.90/92
	131	19.1/44	18.0/55	18.1/95	10.07/92
	138	18.9/94	17.3/55	18.0/97	10.65/94
	148 ³	19.2/96	16.3/54	18.1/99	11.41/96
	153	19.1/97	15.9/54	18.1/100	11.80/97
	155	19.1/98	15.7/54	18.1/101	11.95/98
HIGH	151	19.4/44	18.2/54	18.2/94	9.86/91
	153	19.2/44	18.0/54	18.2/94	10.00/92
	160	18.9/94	17.4/54	18.0/96	10.52/94
	170	19.3/95	16.5/53	18.2/98	11.19/95
	181 ⁴	19.3/98	15.7/52	18.2/101	11.91/98

Notes: 1. 5th-percentile female.
2. 50th-percentile female.

3. 50th-percentile male.
4. 95th-percentile male.

5. 3WR/5FL EA SYSTEM 30-DEGREE NOSE-DOWN PERFORMANCE

The 30-degree nose-down 42 feet per second baseline crash event results in a 17-degree offset angle between the downward aircraft velocity vector and the seat back. Since both the seat occupant's spine and the energy absorber's extension axis are essentially parallel with the seat back the effective baseline crash velocity for the seat occupant's spine and the energy absorber's extension axis is only 40.2 feet per second and the effective baseline crash velocity acting to pull the seat occupant's torso forward away from the seat back is 12.3 feet per second. As would be expected the slightly reduced 40.2 feet per second effective baseline crash velocity does reduce the maximum energy absorber stroke, but the initial spinal loading is essentially unchanged so that neither the first lumbar peak load is reduced nor is the first DRI peak reduced.

Therefore, for those lowest seat pan supported weights in the three weight ranges where the first maximum lumbar load peak and the first maximum DRI value are higher than the second later values, there is no reduction in the overall maximum values of these two critical parameters in this 30-degree nose-down baseline crash event. However, there is a small reduction of the energy absorber end-of-stroke time of one and two milliseconds for the seat pan supported weights of 131 and 133 pounds. Table II lists the performance as computed for the same eighteen seat pan supported weights in Table I and lists the same data values that were provided in that table.

Table II. The Optimized 3WR/5FL EA 30-Degree Nose-Down System Performance

WEIGHT RANGE	SEAT PAN SUPPORTED WEIGHT POUNDS	MAX. UPPER OCCUPANT ACCEL/TIME g/MS	FIRST MAXIMUM DRI/TIME g/MS	SECOND MAXIMUM DRI/TIME g/MS	EA STROKE DISTANCE AND TIME INCHES/MS
LOW	93 ¹	19.2/46	18.2/57	17.3/92	9.00/90
	102	18.0/45	17.0/56	17.1/95	9.85/93
	111	17.7/96	16.0/56	16.9/98	10.71/96
	116 ²	18.0/97	15.5/55	17.0/100	11.15/97
	120	18.0/98	15.1/55	17.0/101	11.50/98
	131	18.0/101	14.1/54	16.9/104	12.49/102
	133	18.1/102	13.9/54	17.0/105	12.65/101
MID	129	19.3/45	18.2/55	17.2/92	8.98/90
	131	19.1/45	18.0/55	17.2/93	9.13/90
	138	18.3/44	17.2/54	17.2/95	9.65/92
	148 ³	17.8/95	16.3/54	17.0/98	10.42/95
	153	18.0/96	15.9/53	17.0/99	10.78/96
	155	18.1/96	15.7/53	17.1/99	10.92/96
HIGH	151	19.4/44	18.2/54	17.2/92	8.94/90
	153	19.2/44	18.0/53	17.2/93	9.05/90
	160	18.5/44	17.4/53	17.2/95	9.54/92
	170	18.0/94	16.5/52	17.1/97	10.21/94
	181 ⁴	18.2/96	15.7/52	17.1/99	10.89/96

Notes: 1. 5th-percentile female.
2. 50th-percentile female.

3. 50th-percentile male.
4. 95th-percentile male.

The reduction in the EA Stroke distance and the EA stroke time is not unexpected since the delta velocity along the axis of the seat occupant's spine and of the energy absorbers in this 30-degree nose-down aircraft attitude is only 40.2 feet per second for the baseline crash event which results in a kinetic energy level that is only 91 percent of the kinetic energy in the 13-degree nose-down worst case 42 feet per second baseline crash event. Figure 4 includes three graphs of the optimized low, mid, and high weight range energy absorbers with the computed strokes of the stitch ripping energy absorbers for most of the seat pan supported weights considered in the optimization study for the 30-degree nose-down pitch aircraft attitude.

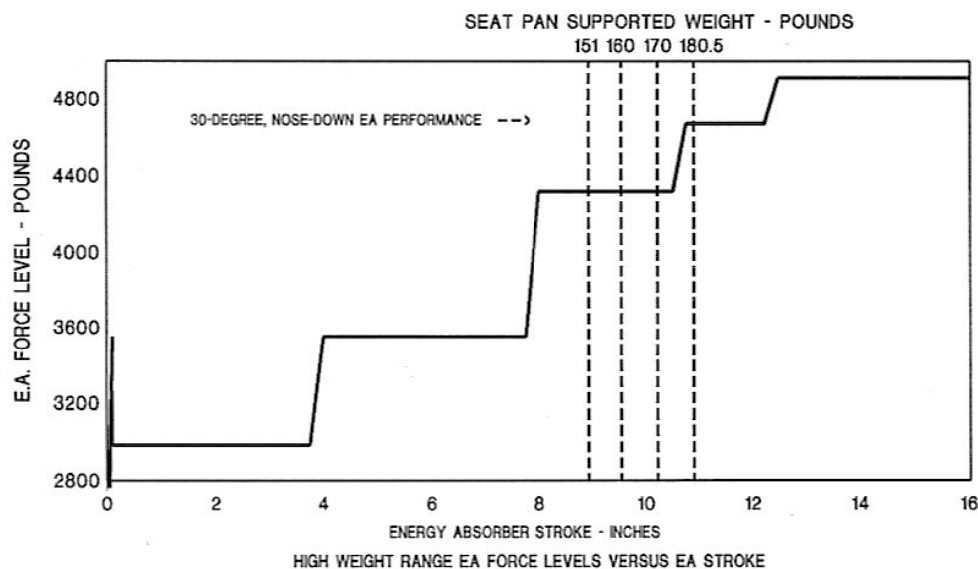
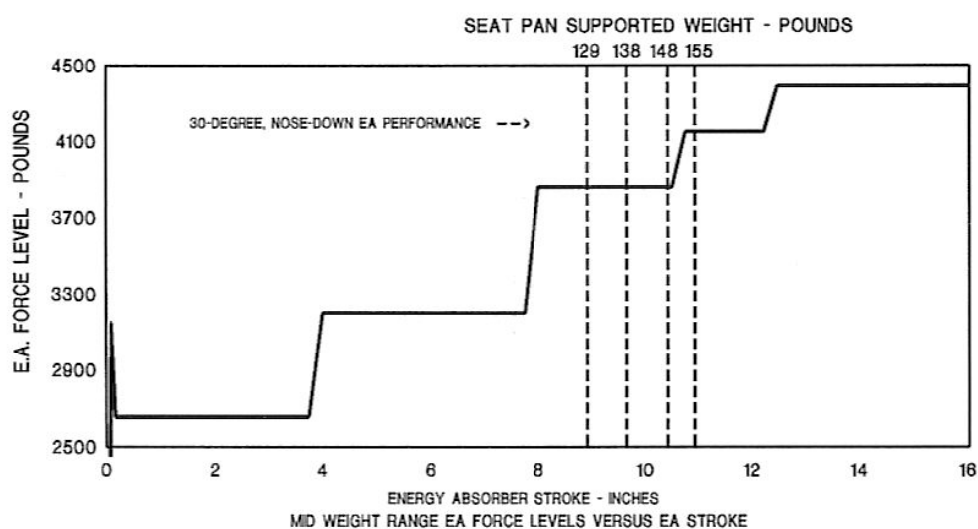
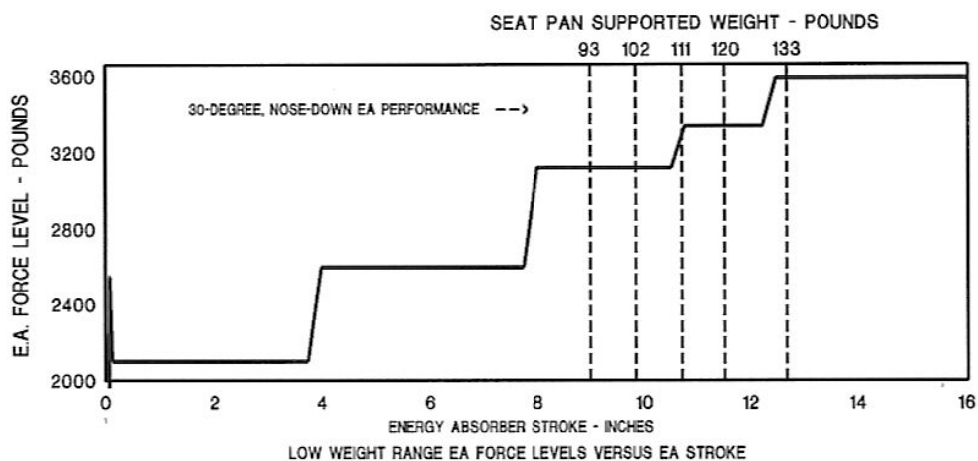


Figure 4. EA performance, 30-degree nose-down, for the three weight ranges

It is believed that some discussion is necessary relative to the differences between the 3WR/5FL EA system and the Variable Profile Energy Absorbing (VPEA) system which explain why the 3WR/5FL EA system is able to provide exceptional performance in the 30-degree nose-down baseline crash event while the VPEA could not. Figure 5 provides in one graph the energy absorber force levels used by the three weight ranges throughout their total stroke. Figure 6 is a copy of Figure 30 on page 64 of TR-97256A which provides similar information for the VPEA force level profiles (note that two VPEA's are used in each energy absorbing crew seat to provide the desired total EA force level) for the 3rd percentile female, the 50th percentile male and the 95th percentile male seat occupants. There is an obvious two-fold difference between these two energy absorber systems. First, the notch load in the VPEA is constant throughout the total weight range of aircrew members such that the important initial deceleration level for the heavier crew members will be much less than desired because the smallest female crew member has set the maximum level for this very critical notch load. In contrast the 3WR/5FL EA system has three different notch force levels such that the deceleration level for all the crew members throughout the high weight range is about 50 percent greater than it would have been if it were the same as that for the smallest female crew member in the low weight range. And second, the VPEA hold force level, which does continuously increase with the torso weight of the seat occupant, remains constant throughout its total stroke. In contrast, in each of its three weight ranges, the 3WR/5FL EA system has four different hold force levels, levels 2, 3, 4, and 5, which increase as the EA stroke increases. Both of these features of the 3WR/5FL EA system work to reduce the EA total stroke time for the heaviest crew members in each of the three weight ranges. Therefore, although the EA stroke time for the 95th percentile male in the 30-degree nose-down baseline crash event was about 140 milliseconds with the VPEA system, with the 3WR/5FL EA system the EA stroke time for this same 95th percentile male crew member in the same 30-degree nose-down baseline crash event was between 96 and 97 milliseconds. Figure 2 shows that at EA stroke times of 100 milliseconds or less the downward force component of the restraint straps, which would act to increase the lumbar load, is appreciably reduced from what it would be 40 milliseconds later. This is a very important major performance improvement that makes possible a lumbar acceleration level of 18.2G and a DRI of 17.1 with a total EA stroke of 10.9 inches for the large 95th percentile male crew member in this critical 30-degree nose-down baseline crash event.

There is a further much less obvious difference between these two energy absorber systems as shown in Figures 5 and 6. The initial spike load shear force for the 5th percentile female seat occupant of 2550 pounds in the low weight range of the 3WR/5FL EA system in Figure 5 provides a peak acceleration of 16.7G. The initial spike load shear force of 2694 pounds (2 times 1347 pounds) in Figure 6 of the VPEA provides a peak acceleration of 17.7G. This 1G difference in the acceleration of the energy absorber supported weight of the 5th percentile female can be expected to result in an increased lumbar acceleration of about 1.4G due to the compressibility of her spine. The more probable energy absorber supported weight of the 50th percentile male seat occupant of 207.7 pounds will have only an initial spike acceleration of 15.2G

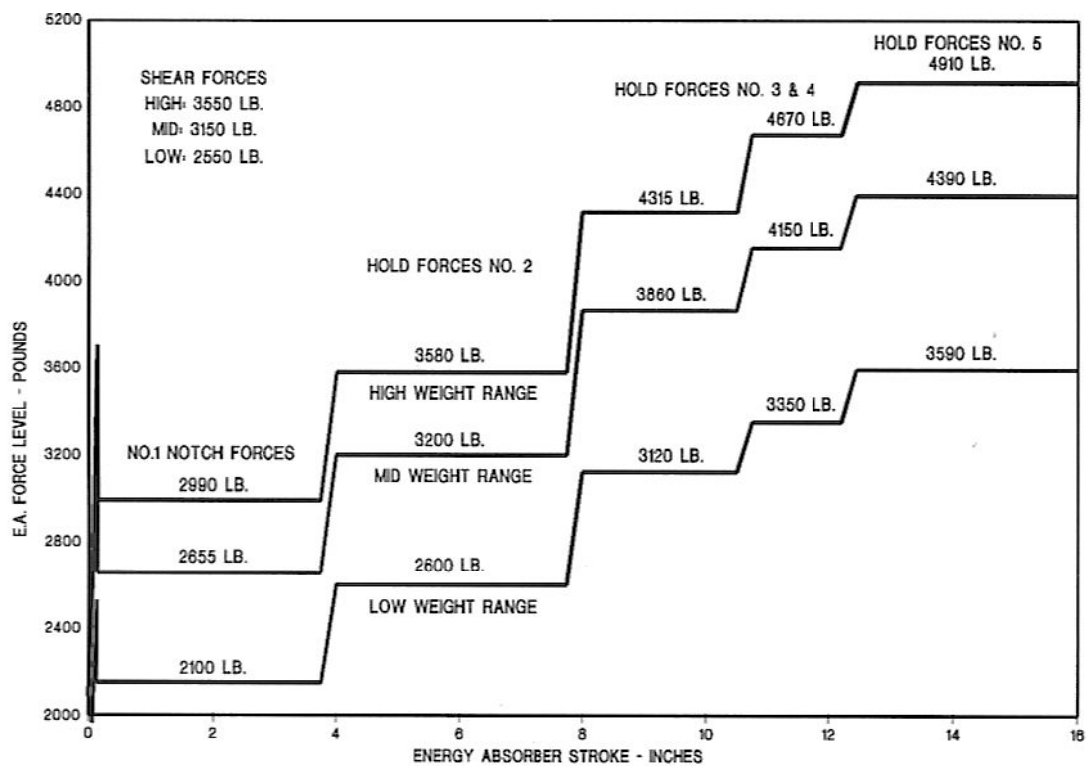


Figure 5. EA force levels versus stroke for the three weight ranges.

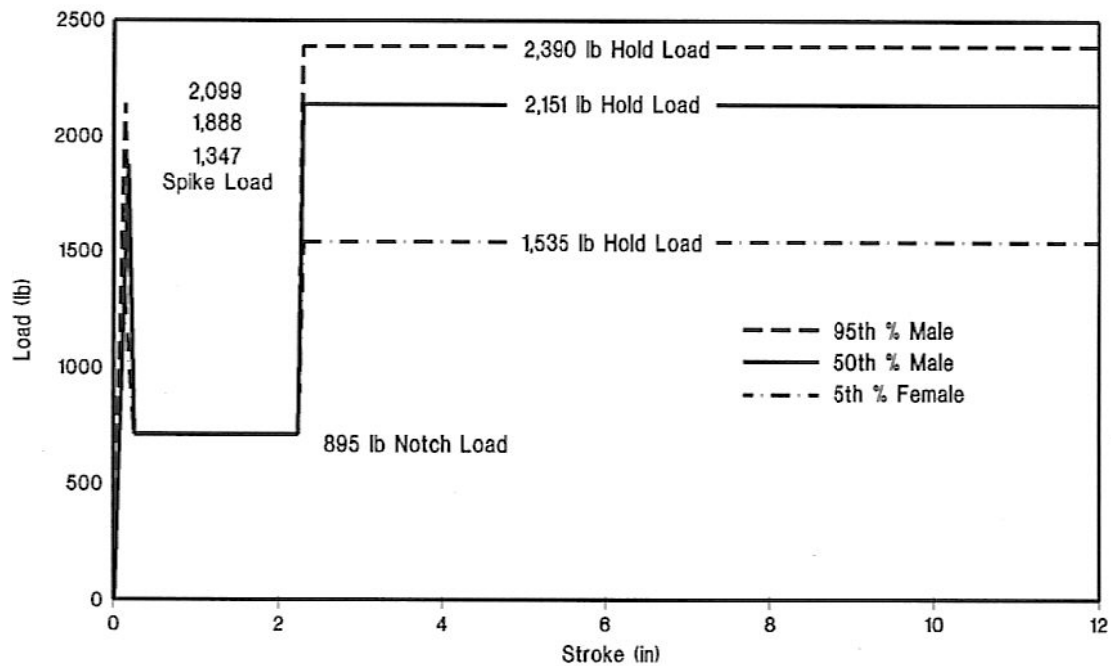


Figure 6. Copy of figure 30 of TR-97256A.

in the mid weight range of the 3WR/5FL EA system while he would have had an initial spike acceleration of 18.2G with the VPEA. This 3.0G greater initial spike acceleration of the VPEA could be expected to result in an initial lumbar acceleration level that would be as much as 4.2G greater than that of the 3WR/5FL EA system for this more average weight seat occupant.

6. SUMMARY AND CONCLUSIONS

The 3WR/5FL EA system will provide the using commands some important capabilities that cannot be provided by any of the existing EA systems. The following important advantages are claimed.

- (1) The total pilot population from the 5th percentile female up to the 95th percentile male will be provided lumbar loads that will be at least 1G less than the acceptable 20.4G lumbar acceleration tolerance even in the 13-degree nose-down aircraft attitude for the 42 feet per second baseline crash event and will be provided lumbar loads that will be more than 1G less than the acceptable 20.4G lumbar acceleration tolerance in the critical 30-degree nose-down aircraft attitude for this baseline crash event.
- (2) The 180.5 pound maximum seat pan supported weight of the 95th percentile male pilot (212.0 pounds body weight) in the high weight range and the 156 pound maximum seat pan supported weight pilot (181.4 pounds body weight) in the mid weight range both have an energy absorber stroke of 12 inches or less even in the worst case 13-degree nose-down aircraft attitude for the baseline crash event and have an energy absorber stroke of 11 inches or less in the 30-degree nose-down aircraft attitude for the baseline crash event.
- (3) The 133 pound maximum seat pan supported weight pilot (152.6 pounds body weight) in the low weight range has an energy absorber stroke of 13.8 inches even in the worst case 13-degree nose-down aircraft attitude baseline crash event and has an energy absorber stroke of less than 13 inches in the 30-degree nose-down aircraft attitude baseline crash event. These greater than 12 inch energy absorber strokes for the low weight range seat pan supported weights are acceptable as the pilots in the low weight range will have the seat adjusted up by one and seven-eighths of an inch or more to have the correct eye level position in the cockpit.
- (4) The cost of this energy absorber system will be less than many, if not all, of the existing EA systems and will be less than the automatic weight sensing Variable Profile EA system evaluated by Simula Safety Systems.
- (5) The total system weight of this energy absorber system should be no more than that of the less capable systems now in service use.
- (6) The 3WR/5FL EA system can be designed to retrofit into existing energy absorbing seats by making use of the energy absorber attachment means already provided in those seats without any major structural modifications to the seat itself being required.

It is concluded that the 3WR/5FL EA system does merit further study using either the SOM-LA model or some other multi-axes model of the crew seat and the human anatomy. Then it should be put through full system testing. These efforts would allow an apples-to-apples comparison to be made between it and the VPEA system and/or

other EA systems. It is believed that the very important results that have come from the extensive efforts carried out by Simula Safety Systems can bear full fruit in the 3WR/5FL EA system when it is placed in use by the armed forces. It will be unfortunate if its unique capabilities are never utilized for the benefit of human beings.

Since it appears that there are very few, if any, unknowns that could arise in a development program of the 3WR/5FL EA system, none of the problems that did arise in the Simula Safety Systems testing efforts on the VPEA system, should be seen in such an undertaking. Even if the restraint straps added a force level equivalent to as much as 2G to the lumbar load near the end of the EA stroke time, between 90 and 102 milliseconds in the 30-degree nose-down crash condition, the 20.4G lumbar acceptable tolerance level would not be exceeded! It is important to note that the position of the 95th percentile male pilot in the schematic picture for the time equal 100 milliseconds in Figure 2 is such that the tie down strap tension will not appreciably increase the lumbar loading and an input to the lumbar load of as much as 2G cannot occur.

REFERENCES

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BIOGRAPHY

Mr. Peck is a senior engineer, analyst with LME, Incorporated. His career history in life saving equipment spans 47 years with the Stencel Aero Engineering Corporation, the Survival Engineering Corporation, and LME, Incorporated. He has been involved in escape system analysis, design, development, testing, and evaluation throughout this time span. Mr. Peck has particularly studied means to provide improved escape system performance throughout the expected ejection airspeed envelope, throughout the specified crewmember weight range, and throughout the altitude/temperature envelope. He studied means to provide safe escape under positive Gz conditions for several years. He evaluated means for providing Mach number immunity to those ejection seats which have seat mounted pressure/airspeed sensors. In 1991, he received the SAFE M. P. Koch Award for significant contributions in the advancement of hardware for safety and survival applications. He conceived the Spinal Preload Piston and conducted a Small Business Innovative Research Phase I and Phase II program that successfully demonstrated the capability of the Spinal Preload Piston to greatly reduce ejectee injury probability in positive G_z ejections. He has recently studied new methods for improving the performance of energy absorbing systems for crashworthy crew seats.