COUNTER BALANCED MOTION (CBM)-DYNAMIC SEATING

New Seat Mechanics to Reduce Occupant Injury and Enhance Comfort

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ABSTRACT

The Counter Balanced Motion (CBM) design utilizes the seat cushion as a crash safety restraint. Just as the air bag becomes a cushion to absorb deceleration forces on the upper body, the seat cushion is used to absorb deceleration forces on the lower body.

Crash simulations of the CBM yield a 33 to 70% reduction in injury loads to the chest and legs. This brings applied forces below bone and joint failure loads.

In addition, impact loads applied to the lower leg become negligible by retracing the feet away from the toe pan and Head Injury Criterion values are reduced 13 to 30%.

The appearance and posture alignment of seats equipped with the CBM mechanism are identical to current production seats. Figure 1.

Figure 1: Seats Equipped with CBM Mechanism

This paper describes the CBM Seat mechanics, design and function. The functional capabilities are verified by three different, independently performed approaches: 1. dynamic analysis, 2. sled tests, and 3. Madymo crash simulations.

INTRODUCTION

The idea of an articulating seat has intrigued researchers for many years. The present approach involves the seat mechanics that work dynamically in conjunction with body mechanics.

It is well known that if a wheel is not centered or properly balanced, the rotating masses in motion at high velocity will shake, producing damaging forces. The CBM Seat dynamics are optimized on a similar principle. If the CBM seat path center is correctly placed, it will function as smoothly and reliably as a properly balanced wheel.

DYNAMIC SEATING PRINCIPLE

The path of seat arcuate motion controls pelvic angle change and, therefore, lumbar flexion. By centering the seat motion proximate to the body's center of mass, (CG) located relative to the center of lumbar motion, dynamic equilibrium can be obtained during the crash pulse and stability during normal driving (1).

The optimal location of this center is described by the equations of motion and verified by computer simulated sled test (Madymo). The seat path and maximum containment angle are essential parameters to use the seat as a restraint.

50 milliseconds is about the peak force time of a 30 g crash pulse. Within this time the body can only be repositioned for deceleration by rotating its parts about its center.

During the first 40 MS from impact, the body will practically be in free flight, the time it takes for the airbag to contact the body and the seat belts to tense. The seat cushion, however, is in contact with the body at 0 MS, the instant of impact, reaching its full 30º deployment at 50 MS. During 0 to 50 MS time, the lower body, gradually restrained, with the legs moving up out of the way, is properly positioned for rapid deceleration by the seat's energy absorption characteristics.

Data produced by the equations of motion, sled test and MADYMO simulations show that seat motion works to reduce crash loads on the body within a defined path and range.

The seat cushion path of motion must define an arc with a center located within a range of 9 cm in front from the center of mass by a range of 26 to 38 cm above the sitting bones. Outside this range, the system does not significantly reduce injury loads. The optimal center, which yields the lowest injury loads, is located about the middle of this range. Figure 2 shows the CBM Seat held in the deployed position.

Figure 2: CBM Seat in Deployed Position.

The seat dynamics that work optimally within the typical mid-size sedan envelope have been determined. It is the path of motion of points on the seat in contact with the buttocks that orbit about a center 33 cm above the seat and 3 cm in front of the body's CG, with a seat pan rise to a 30º containment angle from horizontal.

The CBM seat's optimized path of motion yields the lowest body injury loads during high deceleration, such as the ones induced by a 30g frontal crash.

BACKGROUND

Past attempts to use the seat as a restraint have not produced significant results possibly due to the lack of understanding of the dynamic behavior of the system. There are several patents of record which disclose systems that attempt to use the seat as a restraint. Some move the entire seat with upper back and headrest together. In these designs, the center of motion must account for the rearward path of the headrest and back. The center of rotation of the seat must be raised and its radius enlarged.

Large radii of rotation produce long paths, resulting in leg impact and lower body injury. In addition, the equations of motion show higher head kinetic energy and shear forces to the neck. There are other systems that have small radii of rotation. These stop the pelvis abruptly, causing forces that can compress or shear the spine.

Some systems have combined arcuate paths of seat motion from downwardly to upwardly arcuate. This irregular path of motion does not reduce injuries since it produces a jerk or whiplash in the motion, increasing peak loads and time of deployment. To overcome this deficiency, some systems use outside power sources to deploy the seat cushion such as explosive devices. These designs increase energy, cause high force loads to the body, and are unsafe.

Fixed seats, stiffer belts, high-powered air bags, stiff knee bolsters and belt pretentioners all reduce occupant movement, but increase shear loads to the spine and pelvis, and increase impact accelerations to the face and chest. Therefore, further reduction in movement, to stop the body more abruptly, can cause further injury.

The proper use of seat motion is to control occupant posture as well as guide the body to avoid or reduce contact force with hard surfaces, reduce head strike force and retract legs from the toe pan and knee bolster. The CBM path and range of motion are defined in the CBM Seat technology and patents (4), (5), (6).

The inventive step for the CBM Seat patents is based on the path of seat motion that matches lumbar motion, centered in the proximity to the center of mass of the seated body. This is essential to insure the seat deploys smoothly and before the peak of a crash pulse.

INJURY LOAD TRADE OFFS

Belts and air bags alone do not prevent the lower body from sliding under the air bag and belt (submarining). Adding knee bolsters to stop the forward momentum of the body increase femur fractures. Air bags, which save lives, do so at a force that can cause head, neck, and chest injury and are being depowered.

With the current restraint technology, injury load increases from one part of the body to another are balanced between the forces exerted by the seat belt and air bag. In comparison to the air bag, belts have a relatively small restraining surface.

The CBM Seat adds a third restraint to distribute the loads over a substantially larger surface. Thus concentrated forces applied by the belt and air bag can be reduced about 30%.

The seat can provide a significant increase to the restraining surface on the lower body, loading directly to absorb impact. This reduces the requirements from the airbag and seat belt.

By the time the airbag and belt begin to apply restraining forces, the CBM Seat has already deployed itself by crash pulse force. The pelvis and lumbar spine become properly aligned with the seat to absorb force loads in compression rather than shear. Shear force is known to create significantly more joint and bone injuries at a lower force. For example, the static average tibia failure axial load occurs at 6.4 kN but is only 1.5 to 2.7 kN in shear.

CBM SEAT MECHANICS

To reposition the body and rebalance applied loads, the CBM Dynamic Seating principle is applied.

The CBM roller housing, back frame and upper lumbar supporting members are fixed in relation to the chair mounting floor frame. The curvature of the seat pan mounting tracks defines the primary Center of Rotation (CR) of the CBM mechanism. See Figure 3

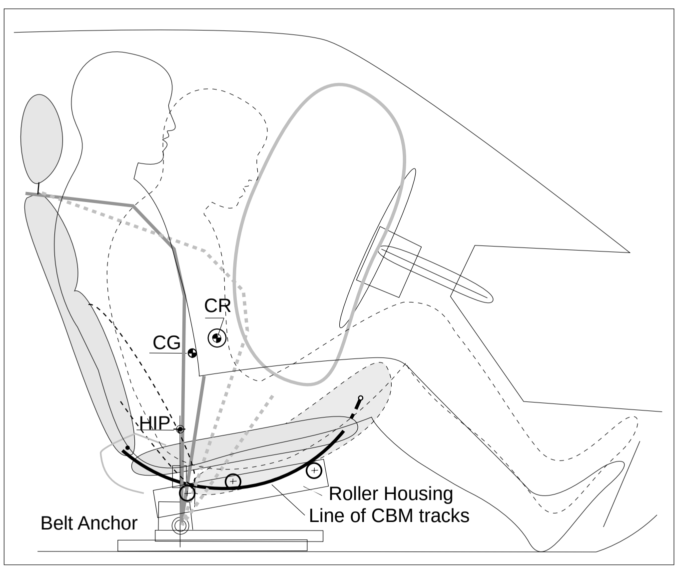

Figure 3: CBM Seat Crash Dynamics

The seat pan is mounted using track and roller housing installed at each side within the frame of current seat pan mounts, with no additional room needed under the seat.

The seat and lower lumbar cushion move along the defined path maintaining the center of the body essentially in a fixed place in the vehicle envelope, both during normal driving and during impact deployment.

An optimized seat belt anchor point location is used with the CBM Seat. The belt attachment point is vertically below the space between the hip joint and the CG of the body. This is designed to balance the forces between belt loads and seat pan loads by proportionally unloading the lap belt to increase the seat restraining contribution.

The CBM Seat is designed to restrain the lower body while reducing head trajectory by maximizing torso translation. This decreases head accelerations allowing safe depowering of air bags.

The original equipment, 50-liter air bag mass flow, is depowered by 20% from 1.5 to 1.2 Kg/s and a 14% elongation safety belt is used in the Madymo modeling. The CBM Seats road tested rotate to 30º from horizontal.

For comfort, the CBM mechanics provides a smooth, self-adjustable seat and lumbar mechanism that maintains contact with the user's body, seeking equilibrium to maintain uniform pressure distribution. The seat adjusts essentially from the body's center.

The CBM Seat moves by the energy generated by the occupant during posture adjustment, allowing lower body motion. After the desired posture is reached, the seat and lumbar remain static by gravity and friction.

Figure 4, shows that at rest and/or at cruising speeds the heels remain on the floor, with the back firmly rested, while the seat and lumbar self-adjust about the CR.

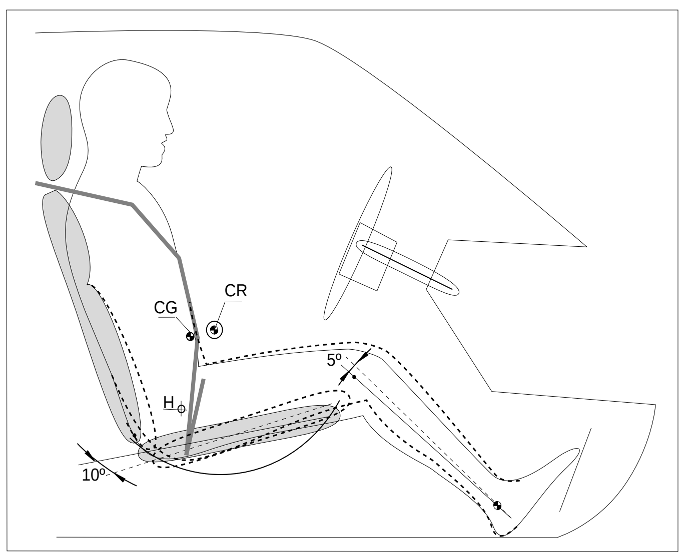

Figure 4: Automatic Lumbar & Seat Tilt Adjustment

A simple motion control mechanism can be installed to control the seat position during normal driving and allow seat deployment at impact. An actuator button that selects a constantly locked or a free mode could be used to reposition the seat. This can be determined by consumer preference.

SLED TEST RESULTS

A popular stock production mid-sized sedan seat modified to include the CBM with lumbar motion was sled tested with a 50%ile Hybrid III dummy from 2 to 28 g. (1) In this early prototype seat, the CR was just outside the optimized area at (6, 24) since it was produced before the optimization methodology was completed.

Six HYGE Sled test runs were performed progressively with the same seat. A typical three-point original equipment harness was used in five belted tests. This was not optimized to correspond to the seat motion. One test was performed unbelted. No air bag was used in any of the sled tests. No seat motion control was installed except for friction.

The CBM trajectory was limited to 25º front containment angle and to 5º rearward, for a 30º total range of motion with pre-run set up of 4º seat pan angle, and a 16º back support angle.

The sled tests show that at 2 and 4 g the seat containment angle increased minimally to 3º. The dummy returned to the initial posture with no effect on feet position, body/seat contact, or visual field up to 4 g. This presents the unlikely need for a motion control device except as an design choice.

Shown in Figure 5, pictures 3 & 6 are pulse peaks for 8 & 28 g. The dummy returns in rebound to a nearly original position. Pictures 4 and 5 show rebound at 8 & 28 g.

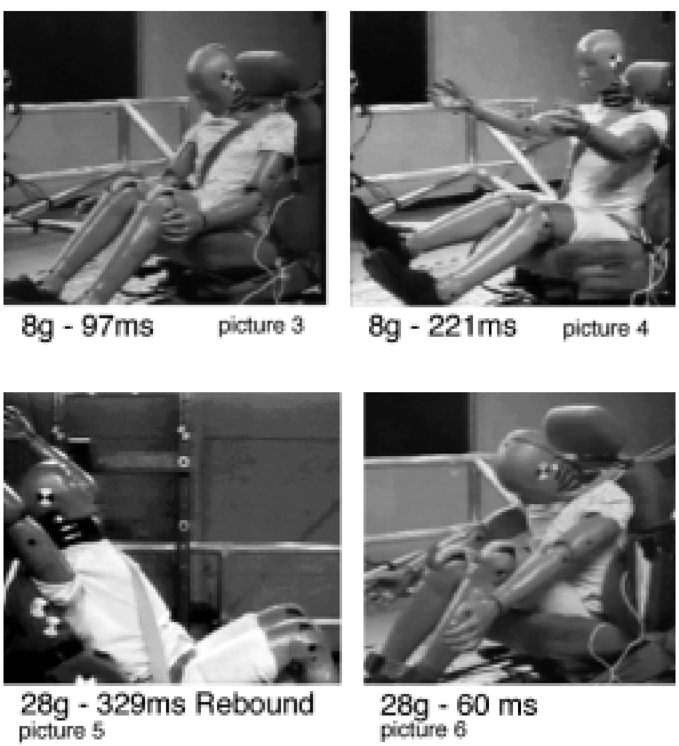

Figure 5: 8 and 28 g test at peak and rebound

The sled test report concluded that the CBM seat deployed consistently, maintained contact with the dummy, returned in rebound, and prevented submarining in all tests. The seat caused the torso to remain more upright, reducing head excursion, chest, and lower torso acceleration. This unoptimized prototype test illustrates the CBM seat's potential to reduce crash loads on the body. The most important finding of the sled test is that the CBM Seat successfully deployed 100% of the time.

OPTIMIZATION METHODOLOGY

To observe the dynamic behavior of the system and obtain the magnitude of forces generated in the body, the equations of motion developed by Dr. Stadler (3) are applied. The free body diagram consists of three rigid bodies of homogeneous mass proportioned to the head, torso and lower body of the 50%ile male, linked at mid lumbar and at the base of the neck. The aim of the optimization criterion is to utilize the seat motion with the path center (CR) that yields the lowest neck shear force and lowest head kinetic energy.

To absorb a deceleration applied to the body, the CBM Seat travels in an upward, arcuate path that complements lumbar motion about the point that represents all flexing of the lumbar spine, the Instantaneous Center of Lumbar Flexion (ICLF) (2). The body masses will tend to rotate about its CG in motion with the seat providing the defined path to catch it within the peak time of the crash pulse. Figure 6.

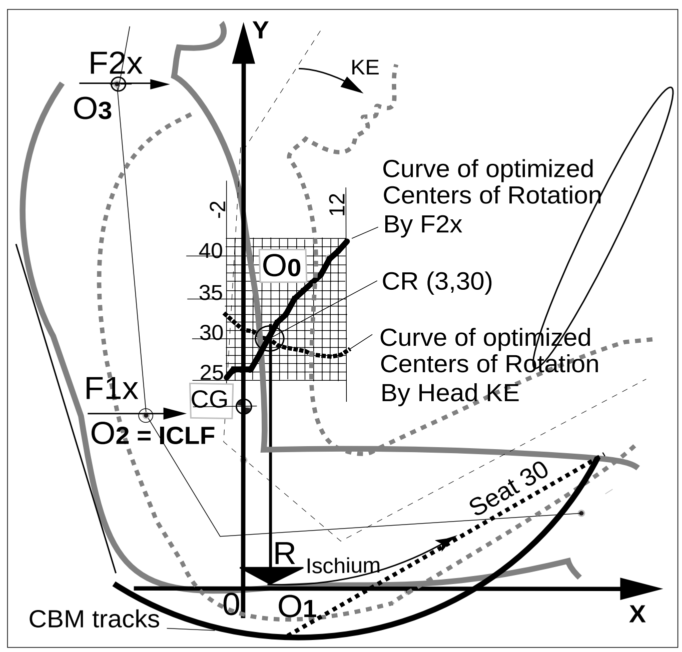

Figure 6: Dynamic Model Setup - Optimized Center.

The equations of motion (3) were run within a location grid of motion centers O0 from x = -2 to 12 cm and with the radius (R = y) between 25 cm to 42 cm, above the sitting bones (ischium) at point of contact with the seat where (y = 0). The shear forces, F1x, at mid lumbar (ICLF), at the base of the neck, F2x, and head kinetic energy KE were obtained for each center in the grid.

The lowest F2x values yielded an optimization curve where forces are between 60.8 N at 1 cm and 496 N at 9 cm for a 30 g frontal acceleration at the instant the seat reaches 30º containment angle.

Figure 7 is composed of the optimized values of F2x, at x=1 to 9. The optimal centers are between x = 2 to 5 cm with a radius of 28 to 33 cm.

X (cm)	Y=R(cm)	KE(J)	F1x(N)	**F2x(N)**	Time
1	26	373.5	1577.4	**60.8**	54.6
2	28	60.4	1308.6	**11.5**	51.2
3	**30**	**3.1**	**1072**	**27.1**	**49**
4	32	41.4	867.1	**89.2**	47
5	33	80.4	751.3	**-74.4**	46.4
6	35	157	588.7	**171.7**	45.4
7	36	200.9	494.1	**115.8**	45.2
8	37	241.8	406.7	**-102**	45
9	38	277.6	330.3	**-496**	44.8

Figure 7: Optimized Centers of Motion by F2x (Newton)

R at 30 cm with x at 3 cm yield low neck shear values of F2x = 27.1 N and KE 3.1 J. In contrast, if we utilize an unoptimized radius, for example R at y = 38 cm and x = 3 cm, neck shear increases to 5492 N calculated. (3)(Not shown in Figure 7.) The magnitude of these forces produce severe injury. This is a clear indication that other paths of motion cannot be optimized to reduce injury loads as their radii would fall outside the optimized curve.

The equations of motion yielded the kinetic energy of the head at each center x, y. This occurs within 44 to 54 MS at the time the seat containment angle reaches 30º.

In Figure 8, the optimized centers of motion by kinetic energy at each x, y location are 3.1 J at 1, 31 to 4.2 J at 9, 28. As can be seen from Figure 6, the points plotted in the curve of optimized centers of rotation by lowest KE intersect at 3, 30 with the lowest F2x shear force curve, indicating the lowest common point of forces and energy values.

R=Y	X=1 KE(J)	X=3 KE(J)	X=5 KE(J)	X=7 KE(J)	X=9 KE(J)
26	373.5	236.5	158.5	118.2	110.1
27	193.1	104.8	58.6	39.6	31.3
28	87.9	39.5	15.6	6.7	**4.2**
29	32	8.8	**2.9**	**4.1**	6.4
30	8.7	**3.1**	9.4	18.6	24.9
31	**3.1**	11.7	27.6	41.4	50.8
32	11.1	29.6	52.3	70.2	83.1
33	26.4	53.9	80.4	102.3	116
34	49.1	81.3	111.3	135.1	150.1
35	75	111.3	143.5	168.2	183.9
36	102	147	175.8	200.9	216.3

Figure 8: Head Kinetic Energy at Each Center (Joules)

Unoptimized systems produce KE's larger than acceptable, even outside the upper limit of 373 J shown. This becomes significant in terms of potential injury considering bone failure energies average between 24 to 92 J. (7)

MADYMO CRASH SIMULATIONS

Optimization of the CBM Seat was applied using the envelope of a mid-size sedan currently in mass production. Madymo crash simulations (8) are compared.

An integrated system approach, including air bags and seat belt systems, is applied. Three dimensional computer model analyses with a 50 percentile TNO Hybrid III dummy is used in all crash simulations. The pre-run distance of the knees to the knee bolster is 20 cm.

To illustrate the effect of optimizing the CBM Seat center of motion and containment angle, results of optimized centers given by the equations of motion are analyzed in relation to four Madymo crash simulations.

The first comparative examination aims to verify the optimal seat angle that maximizes the seat containment contribution. Two Madymo crash simulation results with air bag, without belts, at different seat containment angle rise are compared in Figure 9.

CBM - CR	(5,33)	(5,33)
Seat Angle	**26**	**32**
Unbelted	**0**	**0**
Bag Mass Flow	1.2 kg/s	1.2 kg/s
Low Torso 3MS	755	591
Up Torso 3MS	419	424
HIC (36ms)	416	463
HIC (15ms)	249	268
VC: LT-Ab(m/s)	80	56
Neck load	0.69	0.72
RibLoad	3.73	3.73
UpLumUpTor	2.00	2.03
LoLumUpLum	2.41	2.51
LoTorLoLum	1.82	2.09
FemurL	**6.72**	**3.34**
FemurR	**7.11**	**3.14**
UpTibiaL	**7.82**	**2.47**
UpTibiaR	**8.35**	**2.78**

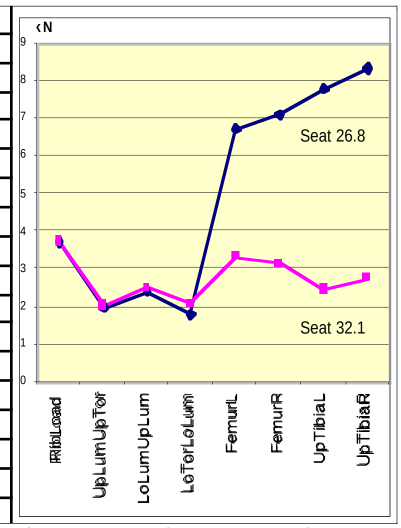

Figure 9: CBM Peak Loads at 26º and 32º Seat Rise

All set up parameters in both runs are exactly the same except that, in one, the seat containment angle is limited to 26º and, in the other, the seat containment angle is limited to 32º. In comparing the results of these two runs, we see that a 6º rise increase in seat containment angle yields a substantial decrease of over 50% in axial loads for the femur and tibia. This is due to the seat's ability to retract the legs from the toe pan and bolster. The significance is that at 26º max seat angle femur loads of 7.1 kN are above joint and bone failure (4 to 6 kN). The 32º run shows a 53% decrease to 3.3 kN, at below failure loads. This is likely to save lower body injury.

Figure 10 shows two Madymo crash simulations with two different centers of rotation but with identical setup parameters including seat angle rise, air bags and belts.

CBM - CR	(5,33)	(3,30)
Seat Angle	32°	32°
Belt Elongation	14%	14%
Bag Mass Flow	1.2 kg/s	1.2 kg/s
LoTorso 3MS	729	665
Up Torso 3MS	535	491
HIC (36ms)	492	481
HIC (15ms)	377	368
VC LT Ab(m/s)	717	701
Neck load	0.25	0.11
RibLoad	6.03	5.46
UpLumUpTor	3.75	3.55
LoLumUpLum	4.1	3.92
LoTorLoLum	2.91	2.7
FemurL	1.02	0.84
FemurR	0.93	0.67
UpTibiaL	0.61	0.54
UpTibiaR	0.48	0.36

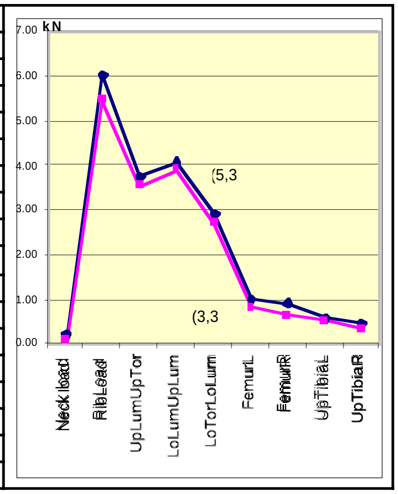

Figure 10: Peak Loads at Centers (5,33) & (3, 30)

Madymo results show that with the CBM center relocated from (5, 30) to (3, 30), about 3.6 cm closer to the CG, Head Injury Criterion is lowered by 2.3%. Torso injury parameters and rib loads are reduced between 8 and 10%. Lumbar axial loads are reduced between 4 to 7% and femur loads are lowered by 18%. These reductions are consistent with the results of the equations of motion which show reduction of forces and energies. The head Kinetic Energy at (3,30) CR is 3.1 J with neck shear 27 N. Both of these are lower than at the (5, 30) CR where the KE is 80 J, and shear is 74 N.

The following Madymo Model crash simulations compare Fixed seat original equipment Vs. CBM Seat with center (CR) at (3, 30), both belted and unbelted.

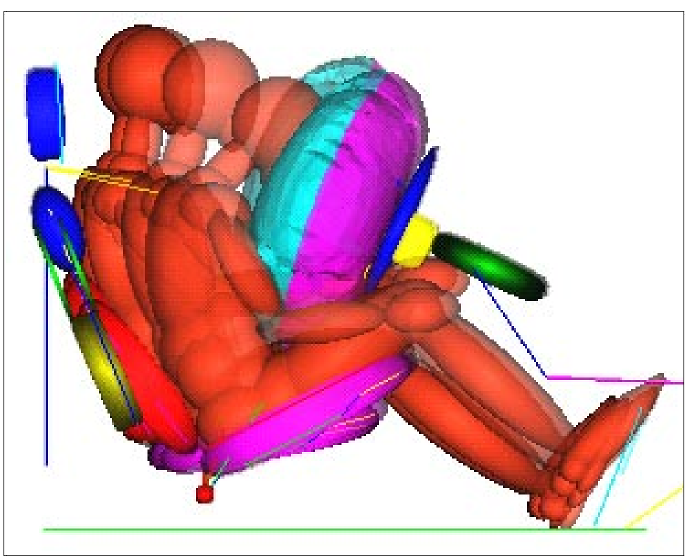

Figure 11: CBM Seat - Madymo Crash Kinematics.

Shown in Figure 11 are the kinematics of a 30 g frontal crash at 0 MS, 25 MS, 50 MS, 75 MS with belts and air bag. The seat contained the lower body, maintaining leg safety by preventing impact with the knee bolster and toe pan. No slippage is observed between buttock and seat.

The upper body moves forward as the lower body rotates counter balanced. The knees move up. The ankles are prevented from compressing against the toe pan. Note the room left between the knees and bolster line to accommodate a higher frontal crash acceleration.

The values obtained with the CBM Seat at CR (3, 30) and a 32° deployment angle, with a 20% depowered air bag and 14% belt elongation, are shown in Figure 12. These are compared to the original equipment fixed seat injury load values.

Head Injury Criterion is lowered with the CBM Seat by13% to 30%, from 554 to 481 and 478 to 368. Rib loads are also lowered 33% from the 8.1 kN level to 5.46 kN as compared to the vehicle with its original fixed seat, belt harness and air bag equipment.

	CBM	Fixed
Seat Angle	32°	16°
Belt Elong	14%	8%
Bag MassFlow	1.2kg/s	1.5kg/s
Low Torso 3MS	665	684
Up Torso 3MS	491	623
HIC (36ms)	481	554
HIC (15ms)	368	478
VC LTAb(m/s)	701	1049
Neck load	0.11	1.05
RibLoad	5.46	8.1
UpTibiaL	0.54	0.54
UpTibiaR	0.36	0.81
MidTibiaL	2.49	3.73
MidTibiaR	2.38	2.53
LoTibiaL	1.89	6.2
LoTibiaR	1.81	2.87

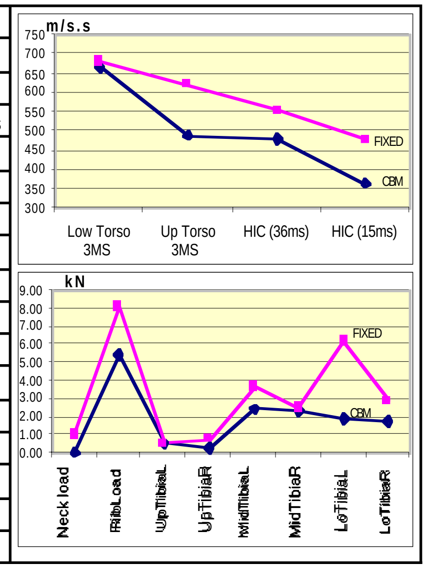

Figure 12: Madymo Crash Simulation - Peak Loads

Compression loads at mid lumbar increased 18% with the CBM Seat, from 3.3 to 3.9 kN. A 70% injury load reduction in the low tibia (from 6.2 to 1.89 kN) is gained with the CBM Seat. The results indicate that the CBM Seat can reduce injury in a 30 g crush, whereas, in the current restraint technology, chest and leg injury are likely to occur.

In the next two Madymo crash simulations, with air bag unbelted comparison runs, CBM vs. Fixed seats, at 30 g were performed both with the identical set up, except belts were not used. See Figure 13, 14 and 15.

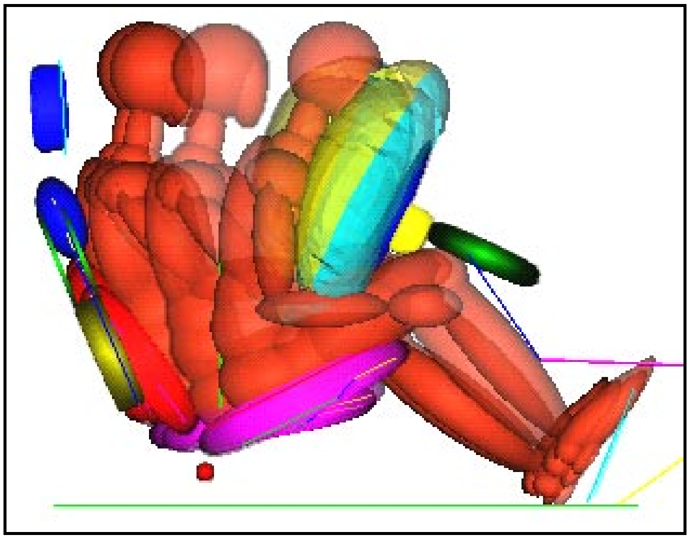

Figure 13: CBM Seat - Unbelted Crash Kinematics

In Figure 13, we see as the body moves forward, the knees move up, with the heels remaining away from the toe pan. In addition, space is maintained in front of the upper tibia. At the peak of the crash pulse shown in the forward posture in contact with the air bag, the seat and buttocks are in firm contact.

Reduced leg impact force with the knee bolster and toe pan is observed. The seat controls the body's rotation and translation, moving the legs toward a fetal position.

In Figure 14 with the seat fixed, the body slides forward the length of the seat until the leg impacts the bolster with considerable knee and foot penetration.

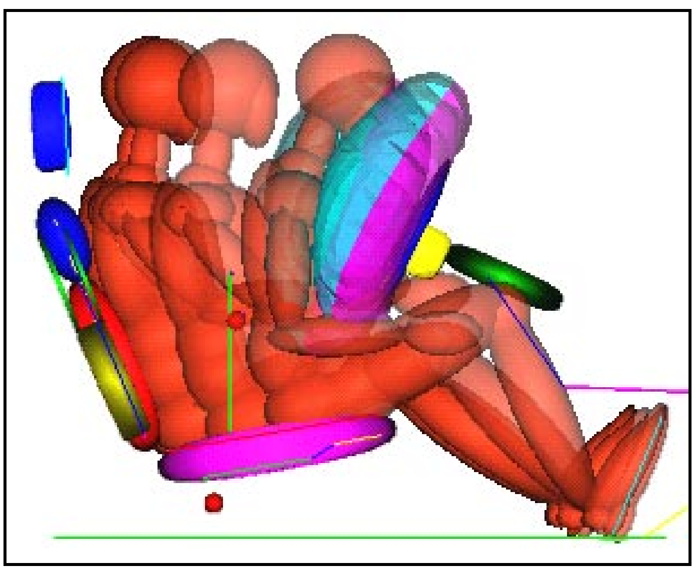

Figure 14: Fixed Seat - Unbelted Crash Kinematics.

In both runs the mid tibia contacted the knee bolster with significantly different results.

	CBM Seat	Fixd Seat
Max Seat Pa	31.9º	10º
Air Bag Mass	1.2 kg/s	1.2 kg/s
Lower Torso	487	1334
Upper Torso	370	503
HIC(36ms)	435	356
HIC(15ms)	245	222
LtAb(m/s)	75	114
RibLoad	3.62	4.03
femurleft	3.69	16.8
femurright	3.32	16.9
UpTibiaL	2.5	20.5
UpTibiaR	2.34	20.8
MidTibiaL	2.75	8.77
MidTibiaR	2.72	8.52
LoTibiaL	1.98	1.89
LoTibiaR	1.97	2.02

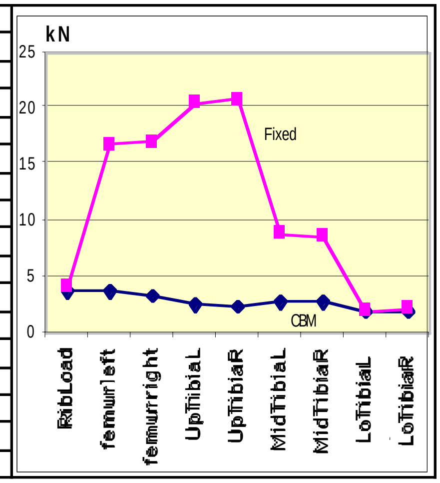

Figure 15: Peak Loads Unbelted - CBM vs Fixed

The results obtained with the seat fixed, unbelted, yield femur and tibia compressive loads at severe injury levels of 16.9 and 20.8 kN respectively. Multiple fractures and possibly a paraplegic life are likely at these injury loads.

With the CBM Seat function, loads are reduced to 3.69 and 2.5 kN. This represents a 63 to 90% reduction in leg injury loads attributed directly to the CBM Seat, which was the only change between both tests. With the CBM Seat, the occupant is likely to avoid lower body injury.

The Head Injury Criterion is lower with the fixed seat without belts by 10 to18% while Upper Torso injury parameters are 26% lower with the CBM. Lower torso injury parameters are reduced 64% from 1334 to 487 with the CBM Seat. This confirms that the CBM Seat restrains effectively preventing lower body injury without belts.

ROAD TEST

The CBM dynamics matches the motion of the body with the motion of the seat, selfadjusting smoothly, while maintaining support without manual adjustments. Fig. 16

Figure 16: CBM Seat Self-Adjustment

During normal driving conditions, the seat and lumbar function to support the body evenly. Leg motion and hand-reach improve allowing easier posture change, lowering fatigue levels in extended driving.

Upon a panic stop, the seat reacts to hold the occupant securely on the seat. The seat and lumbar move into a more supportive angle.

Road testing has met with very positive responses. Drivers and passengers have remarked on the comfort, ease of adjustably, and like the safe feeling of the seat motion.

PERFORMANCE SUMMARY

During crash simulations, the CBM Seat maintains seat contact with the buttocks, remains in place as long as the body mass has forward momentum, and returns in rebound with instantaneous redeployment. In summary the CBM Seat:

1. Increases safety: significantly reduces crash forces on the body and can drastically reduce lower body injuries. Improves the performance of other safety restraints, allowing safe depowering of the air bag.

2. Increases comfort: automatically balances seat tilt and lumbar angle with optimal weight distribution. Passively supports posture change without hand activated adjustment.

3. Is simple, light and cost effective: does not require the cost of any outside power source to function, either for safety or for comfort.

CONCLUSION

The CBM Seat responds on demand of a crash impact pulse and on demand of occupant's posture choice during normal driving.

This experience is supported by the scientific facts as described in dynamic equations of motion, Madymo crash simulations, and sled tests. Tests show that new levels of safety can be reached for improvement in crash survivability and reduction of severe injury.

In addition, the seat's simplified mechanics automatically adjust seat and lumbar angle to improve comfort. The safety and comfort properties of the mechanism complement each other.

The simplicity of use likely will allow the CBM to be an easily accepted safety and comfort system in the automobile.

The CBM Seat uses crash energy to function, providing a reliable passive restraint. Integrating the CBM Seat cushion as an additional restraint helps belts and air bags work well below their critical limits, significantly improving overall occupant safety performance.

CONTACT

Hector Serber is President of American Ergonomics Corporation, Sausalito, CA. He has dedicated the past ten years to developing Dynamic Seating products and designs, obtaining six US Patents and foreign patents in the field. He graduated Technico Mechanico from Collegio Industrial de la Nacion, Buenos Aires. Argentina, 1963 and studied Mechanical Engineering at California State University, Sacramento, USA.

American Ergonomics Corporation is making prototype seats available to vehicle OEM's and seating manufacturers for evaluation and production development.

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