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Test results on the Counter Balanced Motion (CBM) SEAT crashworthiness

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ABSTRACT

This paper reports injury load HYGE sled test data and Madymo crash simulation data, all with a Hybrid III 50%ile male dummy. Six frontal crashes and two rear impacts were performed to determine the effect that the CBM Seat has on injury load data in direct comparison to the original equipment seats (OES),

The test series began with a frontal 12g sled crash pulse with CBM Seats less pretensioners compared to OES seats with pretensioners. It shows that the CBM seat reduced the maximum head trajectory by 10º, neck Moment by 48%, and femur loads by 60%.

In frontal 20 g sled crash pulses without belt pretensioners, the CBM seats yielded 40% lower forces (-2kN to –1.2kN) compared with pretensioners cases. While with pretensioners, they showed a 42% reduction in HIC values (187 to 107).

In a Madymo 30g crash with CBM, belt and airbag, the HIC was 30% lower than with OES seats, from 478 to 368 with CBM. Rib loads were lowered 33%, from 8.1 to 5.46 kN and tibia loads reduced 70%, from 6.2 to 1.89 kN. However, compression loads at mid lumbar increased 18%, (3.3 to 3.9 kN). This can be addressed by improving the cushioning under the pelvis.

In a 21g rear impact test the CBM reduced head trajectory by reducing head and neck rotation 26º. The peak loads show an 18% decrease in HIC and 6% reduction in neck loads. The CBM seat motion pulsed in concert with the vehicle pulse due to momentum increasing the seat containment angle before peak forces. The seat containment angle rises clockwise as seen in Figures 1 and 2 to counteract the lower body 's tendency to escape the seat.

The CBM system accounted for a reduction in injury loads to the legs (36-60%), the neck forces (26%) and HIC values (13-30%) compared to the OES.

INTRODUCTION

The CBM Seat is designed to increase containment angle to eliminate submarining during a crash {1}. In general, the aim of the present study is to determine the effect that the CBM Seat has on the dummy's injury load values compared to the same set up with OES. The subject matter consists of crash simulation cases at low, mid, and high impacts with Hybrid III – 50%ile male dummy sitting belted in a mid size automobile.

The CBM Seat function is equipped with an adjuster tilt/lock mechanism to provide comfort adjustment of the seat and lumbar angle. The lumbar angle is the angle of the lumbar lordosis. In addition, it is the angle that the lumbar cushion has in relation to the seat {2}. This lock can be set to maintain the seat fixed during normal driving conditions, including panic stops and was pre-locked before each of the crash sled cases.

COMPARISON OF FOUR 12G FRONT CASES

The first sled test series, both driver and passenger at 12g - 24 Km/h, {3} consisted of the CBM Seat without pretensioners vs. the OES seat with belt pretensioners.

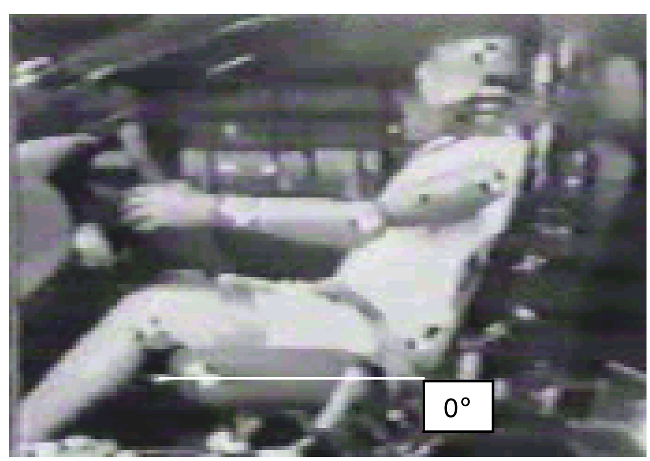


Figure 1: Pre run posture of test with the CBM Seat.

Figure 1 shows the dummy and CBM Seat at t_0, the instant of impact. This is the first crash simulation acceleration to load both driver and passenger side CBM Seats. The CBM Seat tilt/lock control mechanism released the block to the CBM function at 28ms.

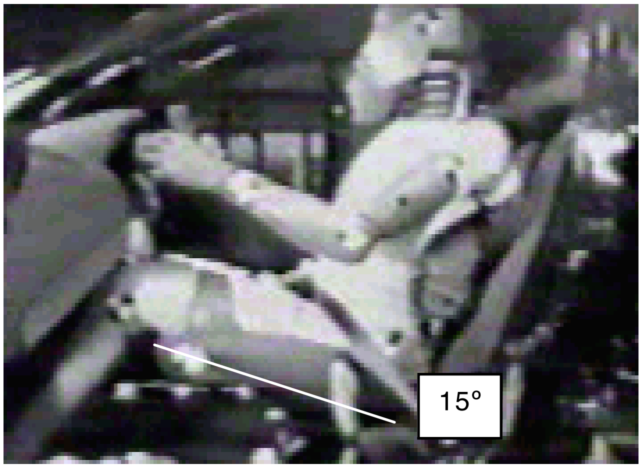


Figure 2: at 75ms, Maximum forward CBM Seat trajectory.

Figure 2 shows the time of maximum forward seat trajectory at 75ms when the seat's side bolster cushion first rotates to 15°. This translates to about 25° containment angle of the seat pan and approximately 63° for the antisubmarine beam surface where the pelvis impact loading deformed the seat structure. HIC values are low in both cases, between 58 and 71 for driver and passenger respectively.


Figure 3: Maximum lower body trajectory with CBM.

The CBM Seat restrains the buttock (the lower pelvis) in conjunction with a lap belt that restrains the top of the pelvis. Figure 3 shows maximum forward lower body trajectory with the dummy's pelvis fully loaded on the seat by momentum. The knee angle is about 85°, thus reducing leg loading. The seat maintains containment angle under load at 55ms to 130ms.

Figure 4 shows the dummy at maximum head trajectory with 115°-knee angle and 20°-neck angle. In rebound, the dummy's lumbar remained in contact with lumbar support maintaining near original posture.

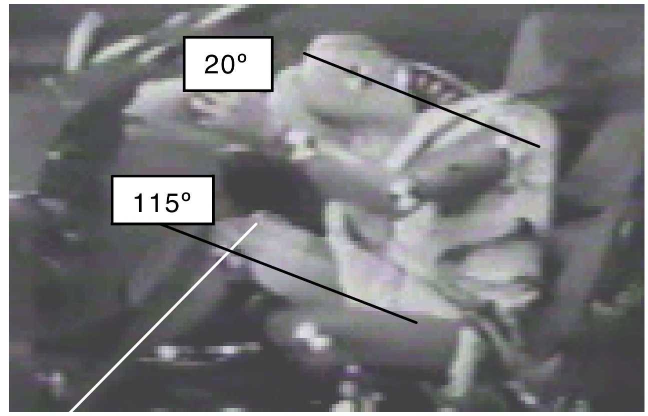


Figure 4: at 150 ms, Maximum head trajectory with CBM.

Figure 5, test with OES, shows the dummy posture at t_0, Figure 6 shows the head, neck, and legs considerably more extended than in the CBM Seat in Figure 4.


Figure 5: at 150 ms Pre run posture of test with OES.

The maximum forward head trajectory is 10° further than with the CBM Seat. In addition, it shows a 146° knee angle with the lower leg extended into the foot well. The CBM mechanism has changed the dynamics that extends and aligns the legs to impact the floor.

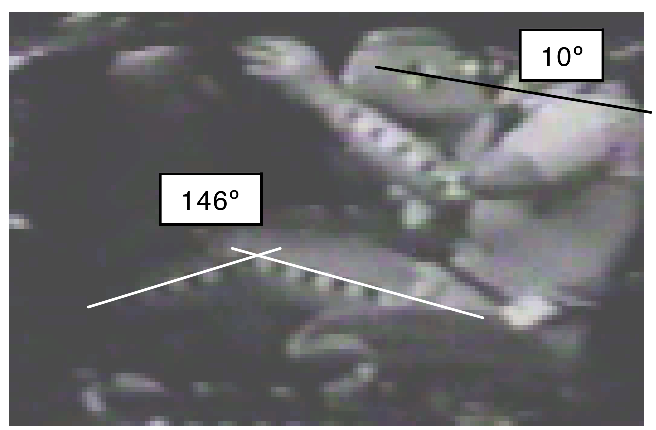


Figure 6: at 150 ms, Maximum head trajectory with OES

In Figure 7, force data from femur shows loads oscillating between +0.3 and –0.4kN in the CBM compared to +0.2

and –1kN in the OES. The CBM appears to show femur loads of 60% less than OES.

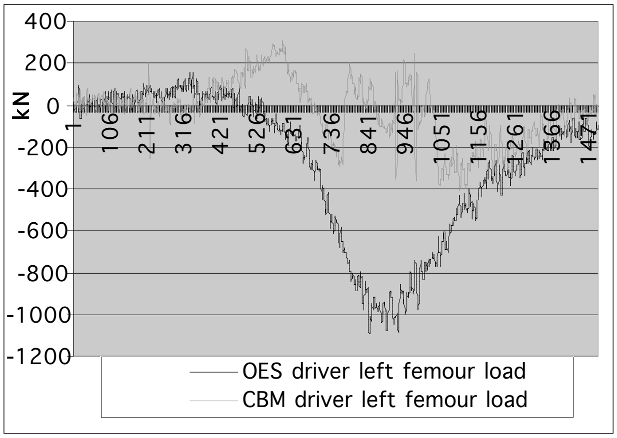


Figure 7: Comparison of femur forces.

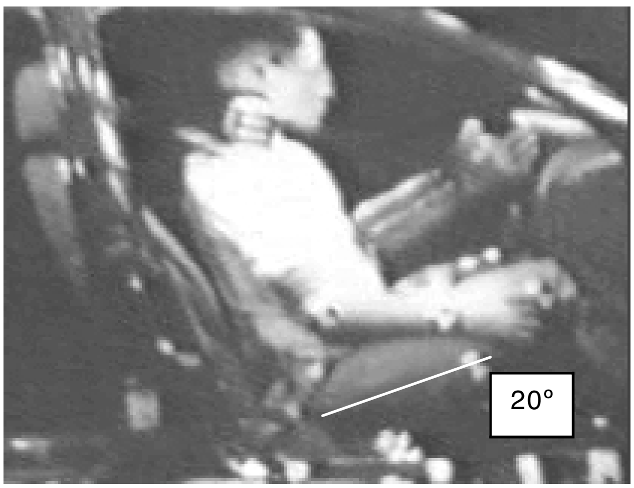


Figure 8: at 75ms, CBM at Maximum seat trajectory.

Figure 8 shows the passenger's buttock loaded on the CBM Seat with the seat at maximum trajectory.

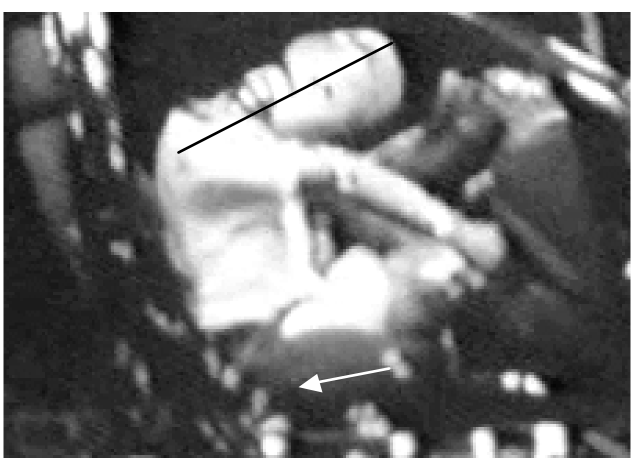


Figure 9: at 150 ms, Passenger at Maximum head trajectory.

Figure 9 shows maximum head trajectory with the seat and lower body during rebound. Figure 10 shows the result of the CBM Seat intervention on the neck loads.

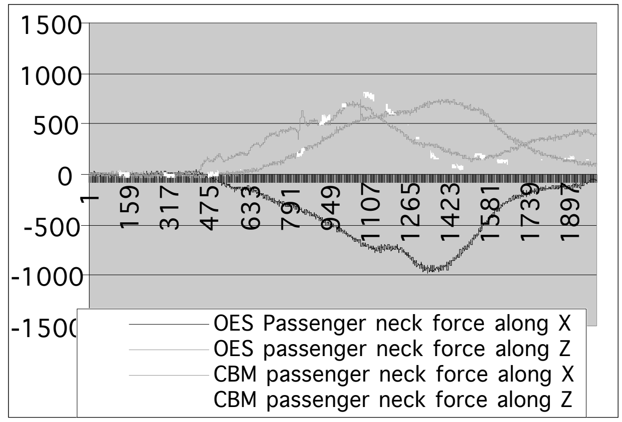


Figure 10: Comparison of neck forces

The graph of neck forces for the OES front passenger shows peak shear (x) forces in the magnitude of –1kN. Whereas the CBM shows a +0.74kN peak force occurring 6ms later. This shows a 26% reduction in neck shear. In addition, the neck Bending Moment with CBM was reduced 48%, (27.4Nm to –14Nm). This shows the CBM function reduces head trajectory, delays the time peak force occurs, and reduces neck shear force.

RESULTS OF 20G FRONTAL IMPACTS

The second sled series, all with CBM seats, consisted of three crash dummies accelerated to 20g {3}. The driver side (CBMa) had a 40-liter Airbag installed in the steering wheel in front of the dummy and the front passenger (CBMb) was without airbag. Both sides tested at the same time in the vehicle and have belts without pretensioners. The second test had the front passenger with belt pretensioners (CBMc).

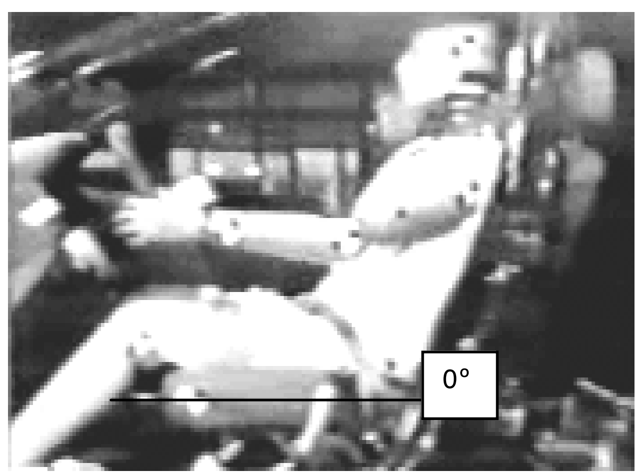


Figure 11: Pre-run posture.

Figure 11 shows the typical pre run posture for all three 20g tests in the second sled series. The CBM seat adjuster tilt/lock control mechanism, designed to lock the seat, released the block to the CBM function at 21ms. The airbag began opening at 35ms. Figure 12 shows CBMa at maximum trajectory.

Figure 12: at 67ms, Seat trajectory (CBMa)

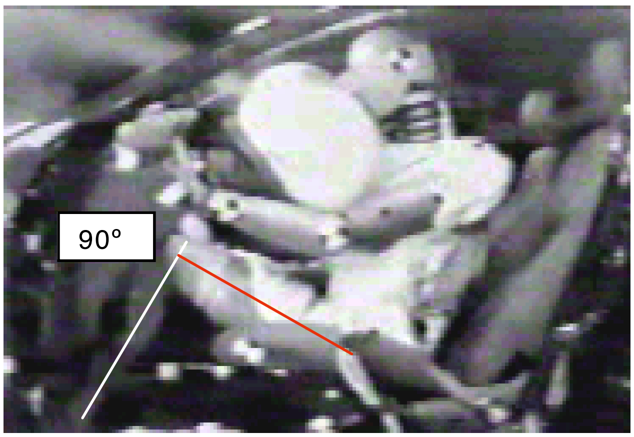


Figure 13: at 80ms, Airbag and face initial interaction.

Figure 13 shows the initial face/airbag interaction (at 80ms). In Figure 14, the maximum forward lower body trajectory occurs at 84ms with a knee angle of 92°.

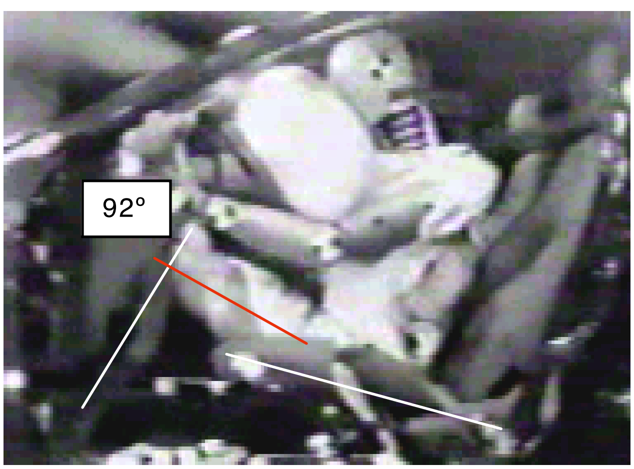


Figure 14: at 84ms, Maximum lower body trajectory (CBMa)

The CBM Seat pan, under peak load, is flexing –3° counterclockwise and the legs are not extended. Figure 15 shows the beginning of the rebound at 100ms. The dummy's pelvis is unloading from the antisubmarine seat pan which regains +2° tilt. The CBM maintains containment angle, 31ms, during the entire forward momentum period. Figures 12 –16 show the thighs firmly contained by the seat and do not submarine.

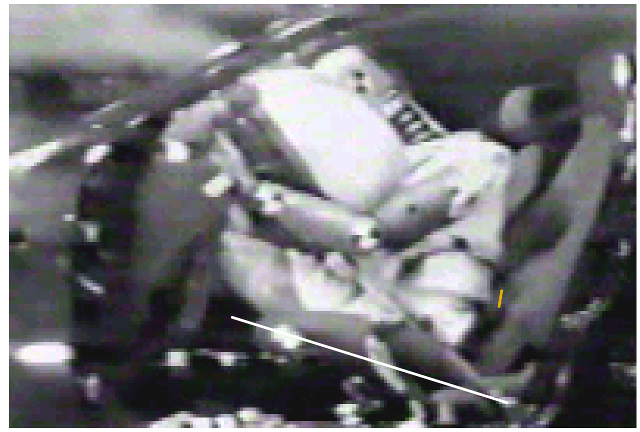


Figure 15: at 115ms, Momentum direction reverse

The maximum head trajectory into the airbag is observed with sufficient distance between the face and steering wheel. At the same time, a -4° counterclockwise rotation of the seat and lower body in rear bound trajectory show all restraints held a safe posture during this sequence.

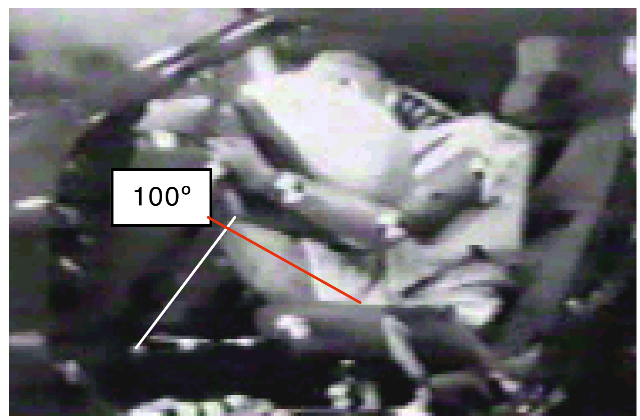


Figure 16: at 115 ms, Maximum head trajectory.

Consistent with the previous 12g test, CBMa shows the changes in the crash dummy dynamics do not extend the legs, thus the CBM Seat maintains low femur forces (0.73kN right leg and 0.79kN left leg).

The next 20g case is the CBMc Seat with belt pretensioners on the front passenger that compares to test CBMb without pretensioners (also on the passenger side). This test is the third sled test to load the same passenger seat. Since the kinematics are similar in all three 20g tests, photos are not shown.

A manual inspection of the CBM function showed light damage from the previous test in the form of increased clearance between the supporting structure and CBM tracks. The adjuster tilt/lock mechanism released the seat at 21ms. Maximum seat trajectory occurred at 92ms with the pelvis loaded on the seat pan. The seat containment angle remained fixed in place during the entire forward momentum period of the lower body. Maximum forward head trajectory occurred at 125ms, with the CBM Seat rebounding to 0° and the legs extended to 115° knee angle, compared to 100° without pretensioners.

The femur load data obtained in the case without pretensioners shows peak loads lowered by, 30- 40 % (reduced from +0.7 kN –1.7 kN to +0.4 kN –1.2 kN). Figure 17 shows the loading for the right legs, similar results recorded on the left legs and on the driver side legs. This indicates that the CBM functions more effectively for the lower body without pretensioners.

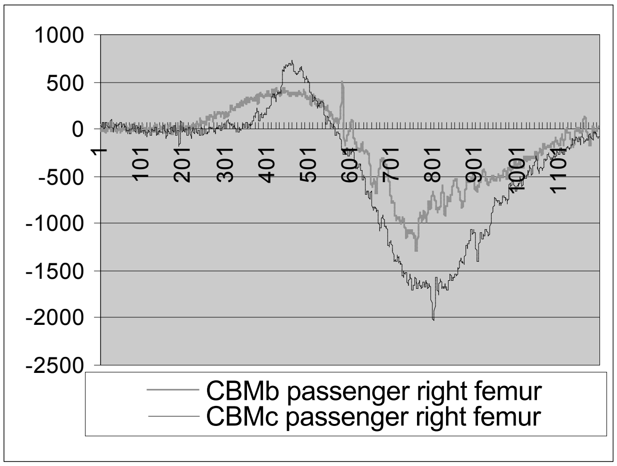
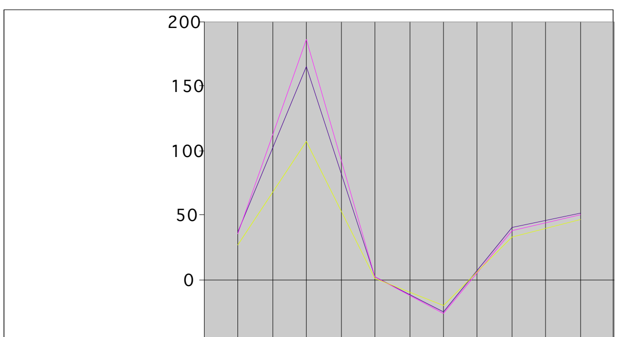


Figure 17: Comparison of femur forces (N).

Pretensioners caused extension of the legs, increasing femur injury loads 30 to 40%. However, Figure 18 shows Pelvis acceleration decreased 6% (from 50 to 47) with pretensioners and upper torso accelerations decreased 13% with the CBM with belt pretensioners (38 –33).



	HEAD-G3mS	HEAD-HIC	NECK: Fz/az-kN/g	NECK Mom-Nm	UpTORS O-G3mS	PELVIS-G3mS
CBMa Drivr (LFt.)	36.7	165	1.43	-25	40	52
CBMb Passeng(Rt	36	187	1.37	-26	38	50
CBMc Passeng(Rt	26.6	107	1.01	-20	33	47

Figure 18: Comparison of Head, Neck, and Torso loads.

In Figure 18, comparing driver to front passenger, both CBM seats without belt pretensioners, HIC values are 12% lower with an airbag on the driver side (187-165). On the passenger side with pretensioners and without airbags, there is a 42% reduction in HIC value compared to case without pretensioners (187-107). It also shows a 26% reduction in head acceleration from 36 to 26.6. The neck moment is 20% lower with pretensioners.

Pretensioners positively enhance the CBM function for the upper body but restrict some of the reduction of leg injury loads. As seen in the 12g tests, there is a 60% reduction in femur loads when compared to fixed OES. Therefore, the net reduction in femur loads is estimated to be 20 to 30% when pretensioners are used with CBM. Tests at 20g are reliable without significant seat structure deformation. With and without pretensioners, the CBM performed well as designed.

COMPARISON OF REAR END CASE.

The pre-run posture of the dummy was slightly different on the CBM seat side. The seat angle was increased to allow rear travel for the seat motion after impact. Figure 19 shows the dummy and CBM Seat at t_0.

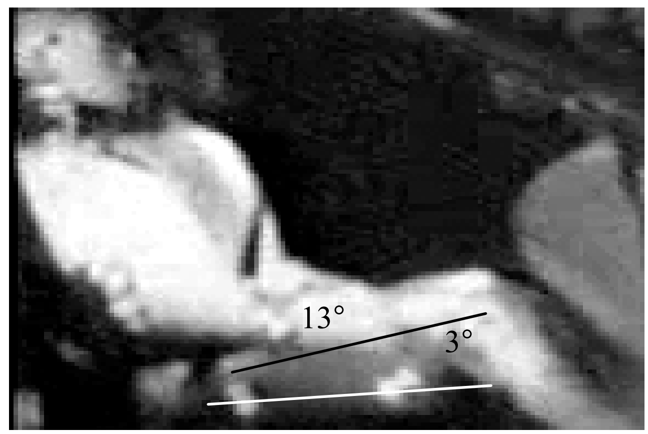


Figure 19: CBM Seat pre-run posture passenger side

In the front passenger CBM seat, the tilt/lock released the block to the CBM function at 40 ms, disengaging the seat and lumbar supports in a timely manner, maintaining constant contact with the dummy's back {3}. Figure 20 shows pre-run posture with the thigh at 11°.

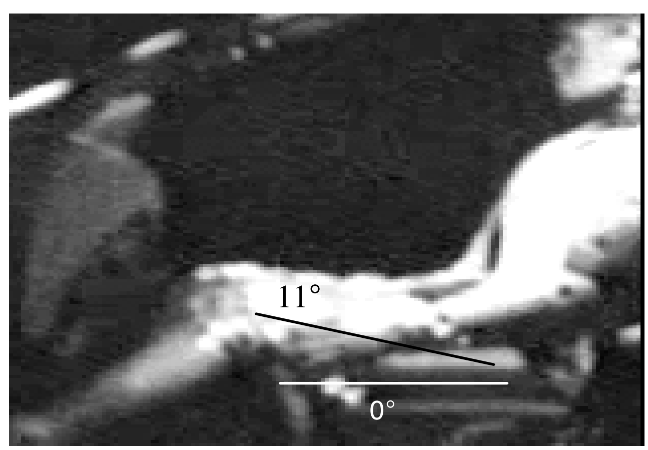


Figure 20: Pre-run posture, driver seat with OES.

The CBM seat rotated back 3° in 19 ms, to reduce rotation of the head before peak forces occurred. Figure

21 shows maximum rearward head trajectory of the dummy on the CBM Seat. The torso and back support are at a 34° angle rearward of vertical.

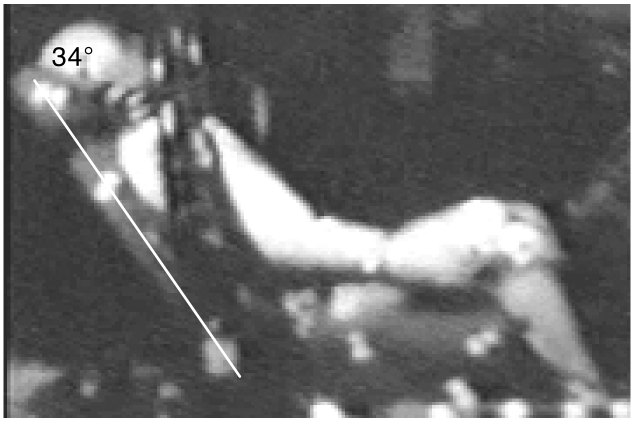


Figure 21: at 128 ms maximum rear head trajectory CBM.

The position of the head at the time of maximum trajectory had a forward neck angle of +6° of vertical as shown in Figure 22.

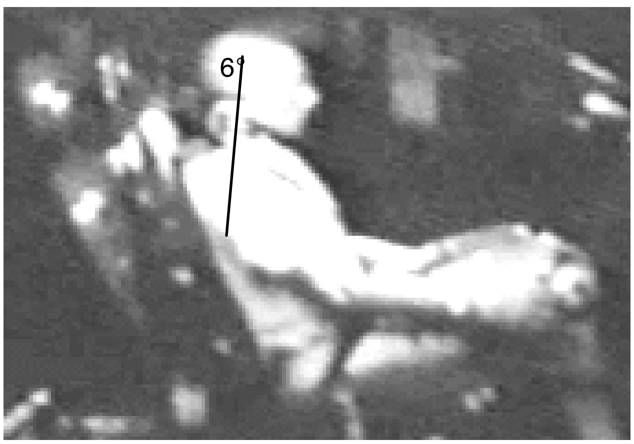


Figure 22: Max. forward rebound trajectory CBM Seat

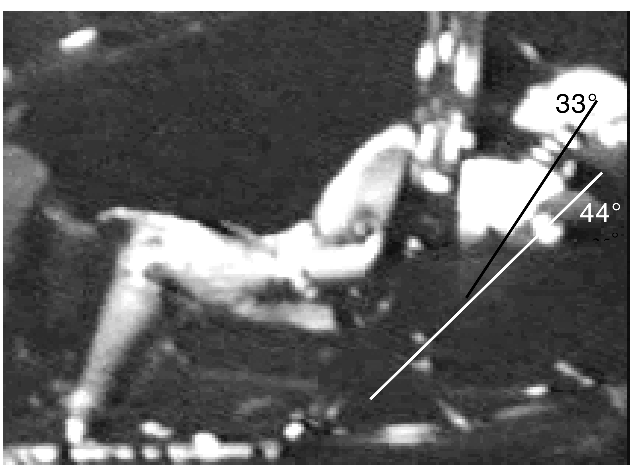


Figure 23: at 144 ms maximum rear driver trajectory OES.

The CBM back frame returned to 25° without deformation. Figure 23, the maximum rearward head trajectory with the OES, is at a 44° angle at peak loads, considerably further collapsed than CBS in Figure 21.

Comparing the maximum forward rebound of the driver in Figure 24 to Figure 22 shows that the CBM caused a 16° reduction of the forward neck angle. The seat back frame of the OES remained reclined at a 35° angle, showing 10° of permanent deformation. In Figure 25, the peak loads registered by the dummy's instruments on the CBM Seat show an 18% decrease in HIC and 6% reduction in neck loads. Femur loads are 50% higher with the CBM but below 1kN. The passenger torso translated about the transverse axes more than it rotated in comparison to the OES

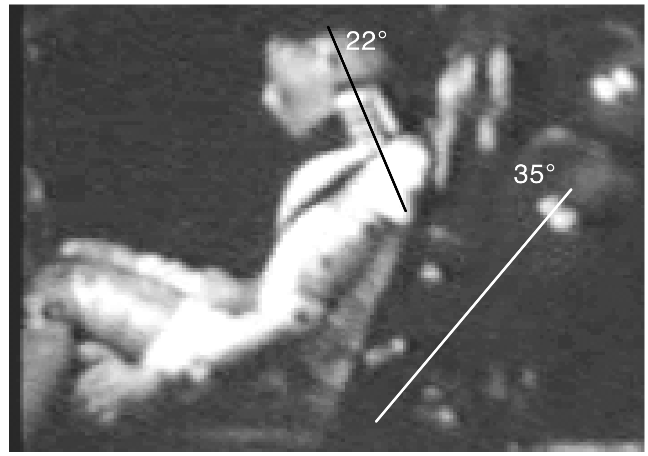
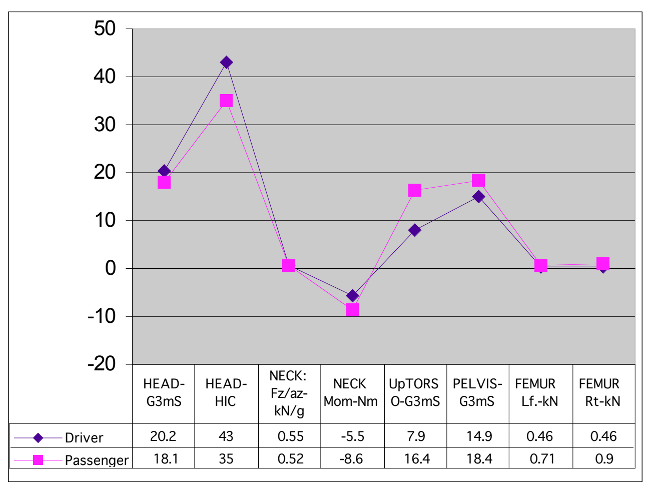


Figure 24: maximum driver rebound trajectory OES

By comparing head and pelvis accelerations recorded on the OES, a 4 g difference (14.9 to 20.2) is observed. In contrast, the CBM shows near even accelerations of 18.1 and 18.4 for the head and the pelvis in Figure 25. This illustrates the shift in energy from the head to the pelvis thus reducing injury forces to the head and neck.



	HEAD-G3mS	HEAD-HIC	NECK: Fz/az-kN/g	NECK Mom-Nm	UpTORSO-G3mS	PELVIS-G3mS	FEMUR Lf.-kN	FEMUR Rt-kN
Driver	20.2	43	0.55	-5.5	7.9	14.9	0.46	0.46
Passenger	18.1	35	0.52	-8.6	16.4	18.4	0.71	0.9

Figure 25. Comparison of Injury loads, rear end crash test.

COMPARISON OF FRONTAL BELTED CASE

The third sled series consisted of two crash dummies accelerated to 32 and 34g with CBM Seat, without pretensioners, vs. an OES with pretensioners {3}. Figure 26 shows the CBM Seat pre-run posture at t_0. During the previous 20g test, the supporting roller housing and belt anchor suffered light damage and metal fatigue. Clearance increased at the CBM track and rollers on the left side. The CBM adjuster tilt/lock released the block to the CBM function at 21ms. The airbag opened at 24 ms.

Figure 26: Pre run posture in test with CBM.

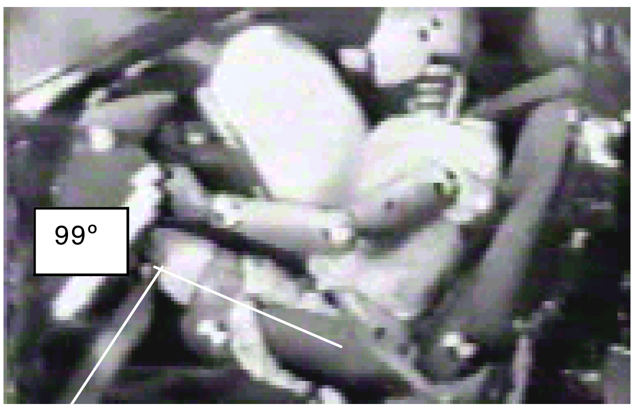


Figure 27: at 55ms Maximum forward seat trajectory.

Figure 27 shows the maximum forward seat trajectory with a knee angle of 99°. The airbag is venting at 10ms before the initial face interaction. At 65ms a 4° seat decline under load occurred. Even though the seat structure deformed during the forward momentum period, the CBM still deployed to a substantial containment angle, causing the legs not to extend.

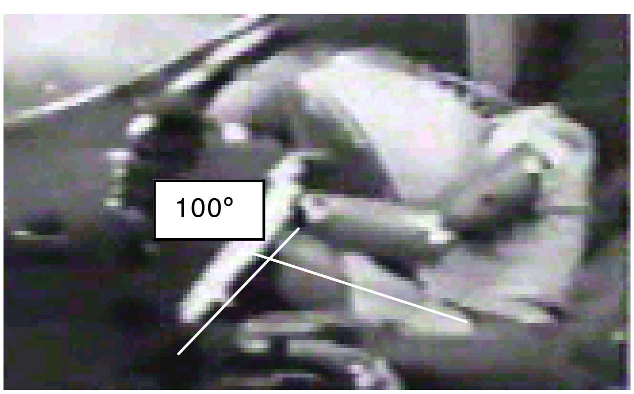


Figure 28: at 105ms Maximum forward head trajectory.

Figure 28 shows the maximum head trajectory. The CBM seat and buttock are in rebound while the head penetrates the air bag impacting the steering wheel.

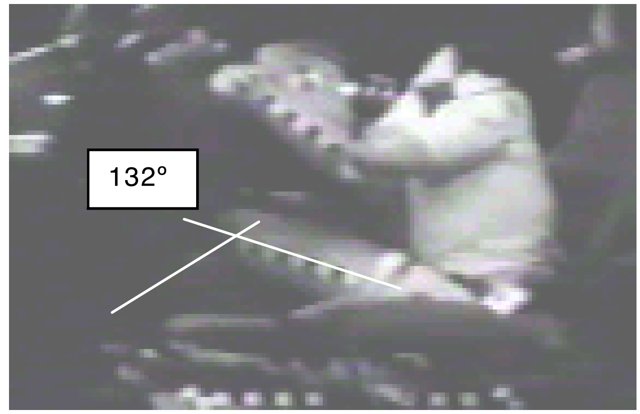
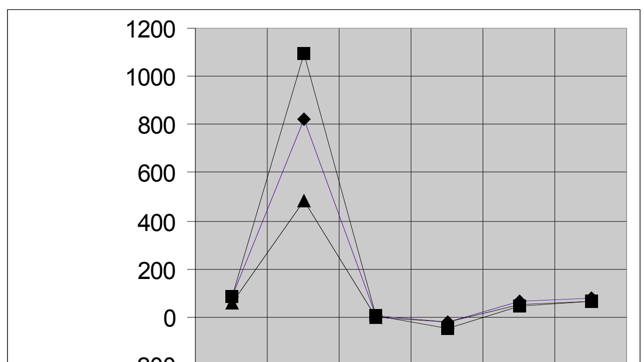


Figure 29: at 105ms Maximum head trajectory for OES.

Figure 29 shows the OES at maximum head trajectory with legs extended and a knee angle of 132°, causing the lower leg to impact the floor. Femur load data shows the left femur with CBM has a narrow peak +4.5kN load compared to a longer duration -2.6kN for OES. This force spike is the result of the seat's structural deformation that reduced buttock loading onto the seat pan. Results of Madymo crash simulation of an optimized CBM Seat at a 30g frontal crash in a similar vehicle with a 50-liter, 1.2 kg/s airbag and 14% belt elongation, yielded the results in CBM-Mady, Figure 30.



	HEAD-G3mS	HEAD-HIC	NECK: Fz/az-	NECK Mom-Nm	TORSO-G3m	PELVIS-G3m
CBM-Sled	82.2	823	2.84	-22.9	67.3	79.7
OES-Sled	86.8	1093	2.87	-49.1	47.1	67.2
CBM-Mady	60.2	481	1.48	-20	49.1	66.5

Figure 30.Comparison of upper body loads.

This data shows that the Neck Moment is 51% lower with the CBM sled case at 22.9 Nm as compared to 49.1Nm with the OES and 20 Nm in the Madymo case when further optimized. Applying to CBM sled results, the 26% reduction in head acceleration by the use of pretensioners, as found in the 20g cases, a 3 ms. cumulative acceleration of 60.8 is obtained. This shows a correlation with sled test results compared to Madymo results of 60.2 to CBM without pretensioners. (4}.

COMPARISON OF FOUR FRONTAL CASES

The forth group of tests consists of four Madymo crash simulation with 50%-H3 dummies accelerated to 30g. The CBM seat CR function moved from the Madymo case sited above. Airbag pressure was lowered by 25% and load limiters to the belts of 7kN for shoulder and 4kN for the lap belt were installed. Lap anchor points were typically mounted over the seat's floor runner frame at 140 mm forward of the OEM case. All parameters of the vehicle interior were held the same. No floor intrusion was used in the model. The Peak load results are as shown in Figure 31 {5}.

50%H3-30g-25%Sofairbag	Belted CBM	Belted OES	Unbelted CBM	Unbelted OES
HIC_{36}	566	660	493	879
HIC_{15}	491	562	383	740
Neck My (Nm)	(-17) (+47)	(-19) (+40)	(-20) (+65)	(-22) (+114)
Neck Fx (N)	(-602) (+132)	(-755) (+7)	(-172) (+577)	(-278) (+1211)
Neck Fz (N)	(-31) (+1725)	(-33) (1584)	(-146) (+3192)	(-79) (+3549)
N_j-NTE	0.48	0.44	0.89	0.98
N_j-NTF	0.52	0.49	0.97	1.13
N_j-NCE	0.071	0.072	0.15	0.14
N_j-NCF	0.11	0.1	0.13	0.23
Chest G's	46	46	54	71
Chest Comp. (mm)	31	35	36	47
LowTors(accel.)	509	472	643	562
FemurLef(N)Comp	(-45)	-440	(-3860)	-5210
FemuRigh(N)Com	(-12)	-646	(-3790)	-5180
TI-UL	0.29	0.5	0.46	0.72
TI-UR	0.33	0.52	0.46	0.71
TI-LL	0.14	0.23	0.15	0.41
TI-LR	0.18	0.23	0.15	0.37
Dumy/SeatPan (N)	3682	50	2500	50
LowTorLowLum(N)	5120	5451	4473	4916

Figure 31: Comparison of CBM/OES belted and unbelted case

The majority of injury loads are lower with the CBM Seat. In the unbelted case, neck-shear loads are 50% lower with CBM at 577N, from 1211N with OES. Neck extension force is 3.5kN with the OES and 3.2kN with the CBM. FMVSS 208 limit is 3.3kN. This indicates that the OES tested is not acceptable under the rules because the neck injury index Nij NTF is 13% over the top limit at 1.13. This is in large due to the 25% reduction in airbag pressure and belt force that was implemented to improve chest G's and HIC values for all four cases. Of twenty injury load values given in each case, only lower torso accelerations are higher in the CBM case, by 14%. Load interaction of the dummy against the CBM antisubmarine beam on the seat-pan caused an increase in restraining loads of3.6kN (50N-3682N). Femur loads are 1.4kN lower with CBM. Lower Tibia index loads TI are 60% lower with the CBM seat. This is partly due to the retraction of both feet from the floor, seen in the kinematics of the Madymo simulation to commence at 57 ms. CBM and OES peak lowTibia Fx loads occurred at 88 and 100 ms, respectively.

SUMMARY OF TEST RESULTS

During 12 to 32g sled tests, the CBM mechanism performed with 100% reliability, functioning in all tests. First, it released the seat tilt/lock at 28 - 21 ms respectively. Second, the seat motion pulsed in accord with the vehicle pulse, increasing the seat containment angle, timely restraining the pelvis during peak forces. Injury loads recorded show a sizable difference between OES cases and CBM. The CBM reduced head, neck, and leg injury loads in all crash modes tested.

CONCLUSION

The efficiency of OES and other restraining systems can be improved with the use of the CBM to operate below critical limits of airbag pressure and belt loads that cause critical bone and joint failure loads, (6-10kN). An optimally proportional load bearing contribution between the CBM Seat, belt harness and airbag systems can be achieved.

The ideal restraining system can take advantage of the fact that the CBM Seat eliminates the submarine mechanism that creates high force loads in the legs while at the same time reducing head injury loads. This ideal restraining system, including the CBM Seat, will provide a net reduction in leg loads in the range of 36-60%, a 26% reduction in neck forces and a reduction of HIC values of 13-30% over the present original equipment restraint system that was tested.

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