EVALUATION OF AN IMPROVED PERFORMANCE ANTI-SUBMARINING SEAT BELT SYSTEM

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ABSTRACT

The objective of the present study is to evaluate a development of the conventional seat belt, offering improved control of anti-submarining and chest loads especially for smaller occupants.

The seat belt continues to be the prime safety system fitted to automobiles. Crash injury data indicates that performance improvements continue to be required, particularly in the rear seat and with smaller occupants in the areas of anti-submarining, adaptation to smaller occupants (such as children making the transition from using child restraints) and chest loads. World interest in simple low cost, lightweight vehicles for use in developing countries is emphasising this need.

The new belt system, the Lifebelt, retains similar belt geometry to current seat belt systems but with an extension of the seat belt webbing in a continuous loop around the upper thighs. It makes use of many available belt system components, and has the potential to allow a simple lightweight seat belt system with acceptable performance, without some of the complex add on systems now being used.

The evaluation began with static fit trials and then used dynamic sled testing under frontal crash test conditions similar to regulatory crash tests (50 km/h and 30g pulse). A number of sled tests (n=20) were carried out in front and rear seat configurations and with different seat structures reflecting current production as well as simplified seating. The new system was compared to conventional belt systems in typical seats and belt geometries. HIII 50M and HIII 5F dummies were used to assess the effect of occupant size, with the small female having the greater tendency to submarine. Anti-submarining effectiveness was assessed from video and with belt motion monitored by iliac spine force transducers, as used for Japan NCAP testing.

The enhanced system retains similar belt geometry and occupant use to current belt systems, with some changes to the seat structure for installation. The new belt with the extra continuous lap loop was shown to give a high level of anti-submarining performance while at the same time retaining good occupant kinetics and keeping the chest loads within acceptable limits. The system is able to reduce the need for add on components (such as the in seat anti-submarining ramp and pretensioners), which are required to give current, conventional seat belts acceptable performance.

INTRODUCTION

Currently, issues regarding the safety of smaller occupants in rear seats, and the effect of seatbelts during rollovers and side impacts are areas of vehicle safety research interest worldwide. Of specific recent concern has been the incidence of ‘submarining’ injuries to smaller seat occupants in frontal crashes, Tylko and Dalmotus (2005) and Kuppa et al. (2005).

In 2005, Kuppa et al reported that in the US 90% of rear seat occupants were seated in the second row of vehicles, with 78% seated in outboard seats. Of these occupants, 64% were restrained occupants in frontal crashes, 78% of which weighed less than 160lbs (72.5kgs), and 64% of which were 12 years of age or younger.

In 2008 an investigation of the US data found that although rear seat occupants accounted for 14% of all vehicle occupants, they accounted for 23% of occupants with injuries and 9% of fatalities, Bilston (2010).

Numerous studies have investigated the location and source of the rear seated occupant injuries, with an overwhelming consensus of a high prevalence of injury to the chest and abdomen due

to interaction with the seatbelt, Kuppa et al (2005), Tylko et al (2005), Zellmer et al (1998).

Cuerden et al (2007) established the lap belt as the cause of 85% of MAIS 1 abdominal injuries and 60% of MAIS 2+ abdominal injuries.

In the study performed by Tylko et al (2005) with HIII 5F and HIII 10YO dummies restrained with the shoulder/lap belt in the rear seat, all experienced abdominal penetration by the lap belt, or very high chest responses. Submarining was seen in all tests bar one exception.

These studies highlight the poor protection afforded to rear seat occupants by current rear seat restraints, particularly in comparison to the ever improving front seat restraint systems, Bilston et al (2010).

Following the work of Mizuno et al (2007), JNCAP from FY2009 assesses the safety of rear seat occupants JNCAP (2009). A group of measures including crash testing, usability evaluation, and seatbelt reminders have been introduced to drive improvements in the safety performance of rear seatbelt systems and to encourage users to wear the seatbelt. During the offset frontal crash test, a HIII 5F dummy is seated in the rear outboard seating position. The HIII 5F is used to assess rear seat occupant chest loads, and any lap belt penetration into the abdominal cavity (submarining) by means of load cells at the iliac crest.

The Lifebelt is a development of the existing conventional seat belt design. It is based on the lap sash seatbelt, with the lap portion of the belt forming a 'loop' around the thighs. See Figure 1. This loop around the upper thighs improves the capability of the seat belt restraint system by minimising the likelihood of 'submarining' in frontal crashes. The enhanced system is a simple and effective system for the safe restraint of occupants in front and rear seats without the need for complex seat structures with anti-submarining pans.

Lifebelt Iteration 1

The development version of the Lifebelt system, Iteration 1, was used in the following tests, comparisons and analyses. The Iteration 1 seatbelt system is shown in Figure 1. It consists of a vertical outboard emergency locking retractor (ELR) with upper D ring (#1), through which the sash belt passes to latch into the inboard buckle (#3) on a flexible stalk angled at 45° in a standard orientation. The slipping tongue (#2) forms the end of the upper lap belt which crosses the lap and passes through a D ring (#4) on the outboard side. The belt continues along the femur on the outboard side of the seat to a D ring (#5) located approximately upper thigh. The lower lap portion runs under the upper thigh to an anchorage (#6) aligned with the D ring, on the inboard side of the seat base. The layout can be seen in Figure 2.

Figure 1. The Lifebelt system (Iteration 1) installed in a vehicle front seat.

Figure 2. Lifebelt Iteration 1 seatbelt system.

TEST SERIES

A total of 20 tests have been performed to date as a part of the proof of concept testing for Lifebelt. The testing was developmental and so includes some tests where component failures occurred. For the purposes of this report, 10 tests have been selected for inclusion. The 10 tests are grouped into four test series for clarity as follows:

- Rear Seat Control Tests,
- Lifebelt 5th % Female Tests,
- Front Seat Control Tests and
- Lifebelt 50th % Male Tests.

The test parameters for the four test series are summarised in Table 1.

Table 1.
Summary of the test parameters

Test (Number)	Seatbelt	Dummy (HIII)	Seat	Sash Load Limiter	Iliac Crest Load Cells	Knee Impact Cushion	Test Facility	Test Date
Series 1 Honda Rear Seat Control Tests								
Control 1 (S090258)	Autoliv	5F	Honda Rear	No	No	No	Crashlab	06/09
Control 2 (D1-4260)	Autoliv	5F	Foam Seat	No	No	Yes	Autoliv	05/10
Series 2 Lifebelt HIII 5th % Female Tests								
Lifebelt 1 (D1-4189)	Lifebelt Iteration 1	5F	Standard Honda	No	No	Yes	Autoliv	02/10
Lifebelt 2 (D1-4258)	Lifebelt Iteration 1	5F	Honda Foam Seat	No	No	Yes	Autoliv	05/10
Lifebelt 3 (D1-4309)	Lifebelt Iteration 1	5F	Honda Foam Seat	Yes	No	Yes	Autoliv	07/10
Lifebelt 4 (D1-4411)	Lifebelt Iteration 1	5F	Honda Foam Seat	Yes	Yes	Yes	Autoliv	10/10
Series 3 Ford Front Seat Control Tests								
Control 3 (D1-4306)	Autoliv	50M	Ford Front	No	No	Yes	Autoliv	07/10
Series 4 Lifebelt HIII 50th % Male Tests								
Lifebelt 5 (D1-4259)	Lifebelt Iteration 1	50M	Honda Foam Seat	No	No	Yes	Autoliv	05/10
Lifebelt 6 (D1-4307)	Lifebelt Iteration 1	50M	Honda Foam Seat	Yes	No	Yes	Autoliv	07/10

The sled testing was performed at two established test laboratories, Crashlab in Sydney, Australia and Autoliv in Melbourne, Australia.

Tests at Crashlab were performed according to the ADR4/03 'Seatbelts' frontal impact test pulse. The peak test acceleration was 27.5 g at 39.2 msec and the velocity change was 43.7 km/h. Tests at Autoliv were performed according to the ECE R16 'Safety Belts and Restraint Systems' frontal impact test pulse. The peak test acceleration was 28 g at 42 msec with a nominal 48 km/h velocity change. These are both severe dynamic test pulses used to certify the strength of seat belt systems fitted to current vehicles.

Anthropometric Test Devices

Hybrid III 5F and Hybrid III 50M anthropomorphic test devices (ATD) are used to represent the restrained occupants in the vehicle seat during the test series. These dummies are specified under the US regulations (the Federal Motor Vehicle Safety Standard FMVSS 208):

- Title 49 CFR Part 572 Subpart O – Hybrid III 5th percentile female test dummy (HIII 5F) and
- Title 49 CFR Part 572 Subpart E – Hybrid III 50th percentile male test dummy, (HIII 50M).

These parts describe the anthropomorphic test devices that are to be used for motor vehicle safety standard compliance testing of motor vehicles and motor vehicle equipment. During this project the dummy positioning was based on Subpart O/E of Part 572. The dummies were instrumented to acquire biomechanical injury data for the head, neck, thorax, pelvis and femur.

Test Seats and Seat Belts

Rear Seat Control Tests A Honda seat was chosen for control testing, as a split folding rear seat typical of those in vehicles currently on the market. The seat is secured to the vehicle at the base of the seatback, allowing for numerous folding adjustments necessary in small multi-purpose vehicles. The Honda seat has a standard 3 point lap sash ELR seatbelt. The seat base consists of a simple flat plywood base with padding. It does not incorporate any form of anti-submarining profile in the seat base.

The seat was mounted to the test sled using the original mounting brackets from the vehicle. The geometry of the seat as tested was as measured in the vehicle. The Honda belt geometry was replicated for the control tests. Standard 'off the shelf' Autoliv belts with vertical ELRs were used in all the control tests.

Front Seat Control Tests A current model Ford front seat was chosen as a production front seat typical of the range in vehicles currently on the market. It incorporates an anti submarining pan and the inboard seatbelt mount positioned on the seat frame.

Lifebelt Tests The Lifebelt Iteration 1 test seat belt components, including the ELR, webbing, D rings, buckle and stalk and anchors were standard 'off the shelf' Autoliv parts. The Lifebelt Iteration 1 tests, presented here, had the lower lap belt mounted to the sled as shown in Figure 3.

The Iteration 1 version of the Lifebelt, discussed here, is the first of the planned developments of the Lifebelt concept.

Figure 3. In board sled mounted anchorages for the Lifebelt Iteration 1 as used in the tests.

TEST RESULTS

Test Series 1 – Rear Seat Control Tests

Test Series 1 consisted of two tests using a HIII 5F dummy restrained in a standard Honda rear seat with the standard seat belt geometry by an Autoliv "off the shelf" seatbelt, Table 1. The Control Test 1 (S090258 – at Crashlab) was performed with the standard rear seat and seatbelt geometry. Control Test 2 (D1-4260 – at Autoliv) used a simple foam seat base, see Figure 4, and made use of an improved seatbelt geometry reflecting developments with the Lifebelt.

Inspection of the vehicle seat following these tests revealed no signs of deformation of the seat or seat anchorages. The seat base remained intact. There were no failures of the seatbelt components. The dummy was effectively restrained in the vehicle seat by the seatbelt in both tests. Seatbelt components were replaced between tests.

The peak response values for the HIII 5F dummies during the tests are included in Appendix A, along with the Injury Assessment Reference Values IARVs for the Hybrid III 5F dummy for comparison, Mertz (1984). An IARV is an industry accepted dummy response value where the risk of significant injury (or AIS 3) to a vehicle occupant would be unlikely, less than 5% risk.

Control Test 1 resulted in the dummy submarining. This was shown by the lap belt riding above the right and left ASIS (or anterior superior iliac spine) and penetrating into the dummy's abdomen, see Figure 4. Control Test 1 showed high chest compression and neck flexion moments with respect to the IARVs plus submarining.

Figure 4. (left) Position of the lap belt in the dummy's abdomen (arrowed) following Control Test 1. (right) Position of the lap belt above the left ASIS (arrowed) following Control Test 2. Note the soft seat base (right) used in Control Test 2.

Control Test 2 also resulted in the dummy submarining, with the lap belt riding above the left ASIS and penetrating into the dummy's abdomen, see Figure 4. Control Test 2 again showed high chest compression and neck flexion moments with respect to the IARVs.

Note: Control Test 1 was run with no knee impact bolster and a slightly different sled pulse (Crashlab sled) to Control Test 2 (Autoliv sled).

Test Series 2 – Lifebelt HIII 5F Tests

Test Series 2 consisted of four tests with a HIII 5F dummy restrained by the Lifebelt Iteration 1 seatbelt configuration in a rear seat, Table 1. The first Lifebelt Test 1 (D1-4189) was performed with the standard Honda Rear seat. The remaining three tests (D1-4258, D1-4309 and D1-4411) used a simple foam seat base, similar to Control Test 2 (D1-4260).

An inspection of the seat post the Lifebelt tests revealed no signs of deformation of the seat or seat anchorages. The seat base and seat back remained in place. There were no signs of failure of the seatbelt or seatbelt components and the dummy and belt remained in place post crash. The dummy was effectively restrained in the vehicle seat by the Lifebelt seatbelt in all four tests. Seatbelt components were replaced after every test.

Appendix B compares the peak response values for the HIII 5F dummy tests with the IARVs for the Hybrid III 5F dummy.

Lifebelt Test 1 performed well in restraining the dummy in the seat, however the upper lap belt moved upwards to rest above the ASIS, see Figure 5. Although there was upward motion of the belt, there was no intrusion or penetration of the belt into the abdomen of the dummy (submarining). The areas of concern in terms of dummy loading during the tests included chest compression levels and upper neck forces.

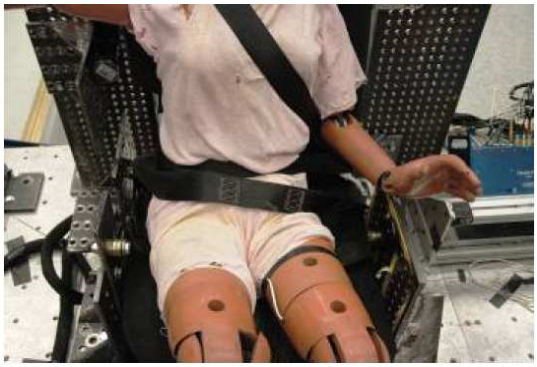

Figure 5. Post Lifebelt Test 1. Note the final position of the upper lap belt was on the ASIS, but not penetrating into the abdomen.

The Lifebelt performed very well in Lifebelt Test 2, with no signs of submarining or dummy instability, see Figure 6. The areas of concern in terms of HIII 5F dummy loading during Lifebelt Test 2 were high chest compression and upper neck forces.

Lifebelt Test 3 was a repeat of Test 2 but with the addition of a sash belt load limiter, which reduced the peak sash belt load from 9.22kN to 5.21kN. The lifebelt performed very well in Lifebelt Test 3 with the lap belt positioned below the ASIS post test, see Figure 6. In Test 3, chest compression and acceleration levels were reduced, however the neck forces remained an area of concern in terms of dummy loading with respect to the IARVs.

Lifebelt Test 4 was a repeat of the Lifebelt Test 3 conditions with load limiter, but Denton ASIS load cells were included in the dummy instrumentation. The ASIS load cells were fitted to demonstrate quantitatively the anti submarine performance of the Lifebelt seatbelt and back up the post test visual inspection used for the earlier tests.

In Lifebelt Test 4, the HIII 5F dummy was stable with good dynamic and kinematic responses, showing no signs of submarining either visually

Figure 6. (left) HIII 5F post Lifebelt Test 2 (D1-4258). (right) HIII 5F post Lifebelt Test 3 (D1-4309).

post test or in the instrumentation responses and had lower chest compression. The loading to the ASIS load cells showed no signs that submarining or unstable belt positioning occurred.

Test Series 3 – Front Seat Control Test

Test Series 3 consisted of a single test (D1-4306) performed with a HIII 50M dummy restrained in a standard Ford front seat.

Inspection of the vehicle seat after the control test revealed no signs of deformation of the seat or seat anchorages. The seat base and seat back remained in place. There were no signs of failure of the seatbelt or seatbelt components on visual inspection with the dummy and belt in place post crash.

The dummy was effectively restrained in the vehicle seat by the seatbelt. There were no signs of instability and submarining did not occur during the test. Note that the seat had an inbuilt anti-submarining ramp and good belt geometry.

Appendix A shows the peak response values for the HIII 50M dummy during the test with the IARVs for the 50th percentile male for comparison. The HIC response and chest compression of the dummy were high in the test when compared with the IARVs.

Test Series 4 – Lifebelt HIII 50M Tests

Two Lifebelt tests (D1-4259 and D1-4307) formed Test Series 4 each with a Hybrid III 50M dummy restrained by the Lifebelt Iteration 1 seatbelt configuration with soft seat base.

Inspection of the vehicle seat after the HIII 50M Lifebelt tests revealed no signs of deformation of the seat or seat anchorages. The seat base and seat back remained in place. There were no signs of failure of the seatbelt or seatbelt components on quick visual inspection with the dummy and belt in

place post crash. The dummy was effectively restrained in the vehicle seat by the seatbelt.

Appendix C shows the peak response values for the dummy during the test with the IARVs for the 50th percentile male for comparison.

The Lifebelt Iteration 1 performed very well in Test 5, effectively restraining the 50th percentile male dummy with no signs of submarining or instability of the dummy, see Figure 7. The level of chest compression was an area of concern in terms of dummy loading with respect to the IARVs.

Figure 7. (left) HIII 50M Post Lifebelt Test 5. (right) HIII 50M post Lifebelt Test 6.

A chest load limiter was introduced into the sash portion of Lifebelt system for Test 6. The Lifebelt performed well in the Lifebelt 6 test, again effectively restraining the HIII 50M dummy with no signs of submarining or instability of the dummy, see Figure 7. The load limiter reduced the chest loading and compression, Appendix C, however these remained slightly above the IARV limit.

DISCUSSION

Anti-Submarining Performance of the Lifebelt

The anti-submarining performance of the Lifebelt is best assessed using the HIII 5F dummy as this smaller dummy is more susceptible to submarining than the larger 50M dummy. The HIII 5F has been used for this purpose as a rear seat occupant in Japan NCAP frontal offset testing since 2009, NASVA (2010).

Submarining, determined by inspection of the post test photographs and the shape of the lap belt load curve, occurred in the two 5F Control Tests, Tests 1 and 2. It did not occur in the Lifebelt Tests 1, 2, and 3 (standard rear seat with soft foam seat base and with or without load limiter).

In the Lifebelt 4 test (D1-4411), in addition to the visual inspection, Denton ASIS load cells were also used with the HIII 5F dummy to demonstrate quantitatively the anti submarine performance of the Lifebelt seatbelt system. With this instrumentation the moment and force readings change to zero when submarining occurs and the belt slips upwards off the load cells. This was not seen during Lifebelt Test 4.

Effect of a Soft Seat Base on the Lifebelt

The effectiveness of the Lifebelt seatbelt system when used with a simple soft foam seat base is demonstrated by comparison of Lifebelt Iteration 1 Tests 1 (D1-4189) and 2 (D1-4258). The Lifebelt seatbelt system prevented submarining with the hard seat base, Figure 5, and the soft seat base, Figure 6. It did not need the seat base design to ensure that submarining did not occur.

The HIII 5F dummy responses for these tests are compared in Figure 8. The neck loads were reduced with the soft seat, Figure 8, and the head excursion increased, Figure 9.

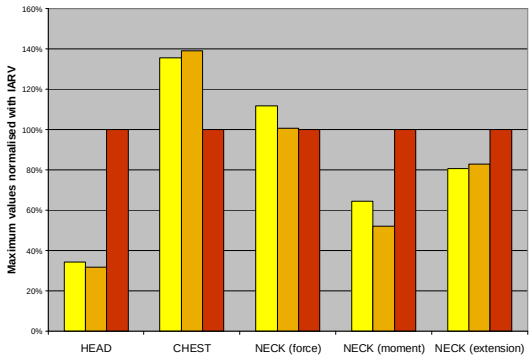

Figure 8. HIII 5F test results of the Lifebelt in a standard rear seat (D1-4189 yellow) and the Lifebelt with a soft seat base (D1-4258 brown). The IARV's for the HIII 5F are shown in red.

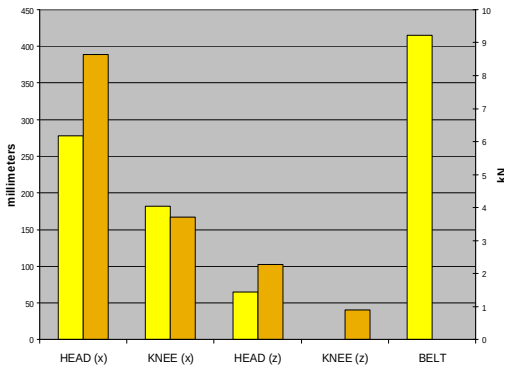

Figure 9. HIII 5F excursion and sash belt load results of the Lifebelt with a standard rear seat (D1-4189 yellow) and with a soft seat base (D1-4258 brown).

Effect of a Chest Load Limiter on the Lifebelt

A comparison of the HIII 5F dummy responses in Lifebelt Tests 2 (D1-4258), 3 (D1-4309) and 4 (D1-4411), demonstrates that including a force limiter in the sash remains an effective means for controlling the chest loads. In each test the Lifebelt seatbelt system was able to prevent submarining both without and with the load limiter, Figure 6. All three tests were with the soft seat base.

The HIII 5F dummy responses for these tests are compared in Figure 10. The chest load limiter reduced the sash belt load and the resultant chest compression to acceptable levels. The neck loads were slightly increased with the load limiter, Figure 10, and the head excursion increased, Figure 11. These effects can be seen in the trajectory of the dummy in the two tests, Figure 12.

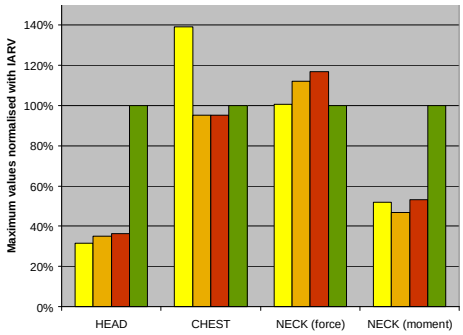

Figure 10. Comparison of HIII 5F performance with the Lifebelt (D1-4258 yellow) and Lifebelt with sash load limiter (D1-4309 brown and D1-4411 red). The IARV's for the HIII 5F are shown in green.

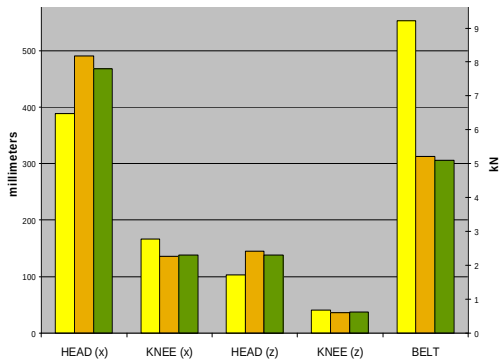

Figure 11. Excursion and sash belt load comparison of HIII 5F performance restrained by the Lifebelt (D1-4258 yellow) and Lifebelt with load limiter (D1-4309 brown and D1-4411 green).

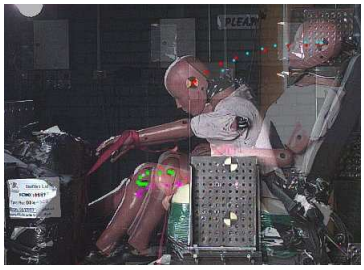

Figure 12. Excursion comparison of HIII 5F performance restrained by the Lifebelt (D1-4258 blue and pink) and Lifebelt with load limiter (D1-4309 red and green).

The HIII 5F Dummy in the Lifebelt

The HIII 5F dummy was fully restrained in the control tests (S090258 and D1-4260). There was no sign of dummy instability, but submarining occurred in both tests, Figure 4.

The HIII 5F dummy was well restrained in the Lifebelt Tests 1, 2, 3 and 4, with the lap belt remaining below the ASIS, see Figures 5 and 6. There was no sign of submarining or dummy instability during the tests.

The dummy responses in the Lifebelt Tests 1, 2, 3 and 4 were very good, especially with the use of the load limiter in Lifebelt Tests 3 and 4, as shown in Figure 13. The chest load limiter reduced the sash belt load and the resultant chest compression to acceptable levels. The neck moments were low with the load limiter, and in this size occupant the head excursion was increased.

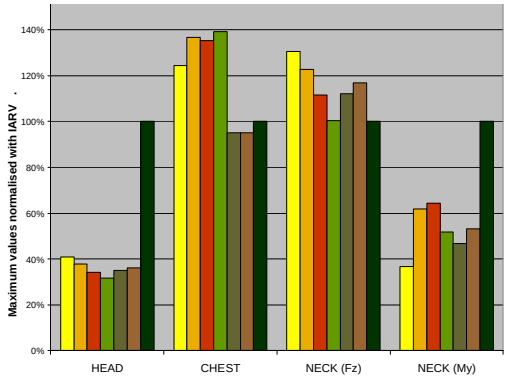

Figure 13. Comparison of HIII 5F performance in the standard rear seat Control Test 1 (S090258 yellow) and standard rear seat with soft seat base Control Test 2 (D1-4260 orange) with the Lifebelt Test 1 (D1-4189 red), Lifebelt soft seat base Test 2 (D1-4258 green) and Lifebelt with load limiter Tests 3 (D1-4309 grey) and 4 (D1-4411 brown). The IARV's for the HIII 5F are shown in dark green.

The HIII 50M Dummy in the Lifebelt

The HIII 50M dummy was fully restrained in the control test (D1-4306). There was no sign of dummy instability or submarining.

The HIII 50M dummy was well restrained in both the Lifebelt Tests 5 and 6, with the lap belt remaining below the ASIS, see Figure 7. There was no sign of submarining or dummy instability during the tests.

The dummy responses in the Lifebelt Tests were very good, especially with the use of the load limiter in Lifebelt Test 6, as shown in Figure 14. The chest load limiter reduced the sash belt load and the resultant chest compression to acceptable levels. The neck loads were reduced with the load limiter, and in this size occupant the head excursion was reduced, Figure 15 and 16.

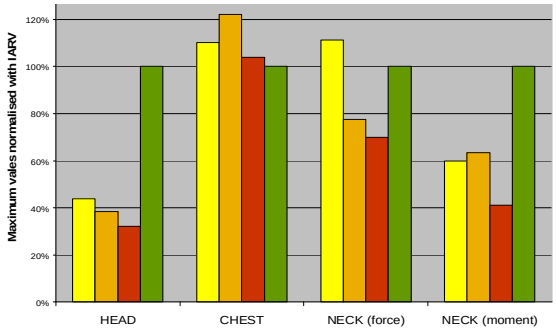

Figure 14. Comparison of HIII 50M performance in the standard front seat Control Test (D1-4306 yellow) and restrained by the Lifebelt Test 5 (D1-4259 brown) and Lifebelt Test 6 with load limiter (D1-4307 red). The IARV's for the HIII 50M are shown in green.

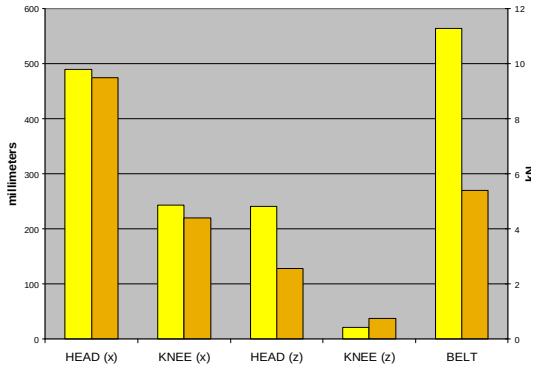

Figure 15. Excursion and sash belt load comparison of HIII 50M dummy performance in Lifebelt Test 5 (D1-4259 yellow) and Lifebelt Test 6 with load limiter (D1-4307 brown).

The test setup was not designed to measure the chest excursion, but based on the video results the Lifebelt HIII 50M tests remained within the ECE R16 chest excursion requirement of 300 mm with the load limiter.

Figure 16. Excursion comparison of HIII 50M performance restrained by the standard front seat (D1-4306 red and pink) and by the Lifebelt with soft seat base (D1-4259 green and blue).

ANALYSIS OF THE FORCES IN THE LIFEBELT SEATBELT SYSTEM

The forces in the Lifebelt Iteration 1 seatbelt system were analysed to define the loading forces acting though the seatbelt, the belt system and on the anchorage points. The test chosen as the worst case loading was the Lifebelt system with a 50th HIII 50M dummy seated on the soft seat base with no load limiter (Test D1-4259).

The Lifebelt system has 6 anchorage points through which the belt loading is transmitted (see Figures 1, 17 and 18):

1. The **SG** (Shoulder D ring) is superior and posterior to the right shoulder of the dummy. Belt tensions T1 and T2 act on this anchor point.
2. The **ELR** (Emergency Locking Retractor) is inferior to the SG. Belt tension T1 acts on this anchor point.
3. The **IB** (In Board) is adjacent to the left hip of the dummy. Belt tensions T2 and T3 act on this anchor point.
4. The **OBA** (Out Board A) is adjacent to the right hip of the dummy. Belt tensions T3 and T4 act on this anchor point.
5. The **OB** (Out Board) is adjacent to the mid right thigh of the dummy. Belt tensions T4 and T5 act on this anchor point.
6. The **IBA** (In Board A) is adjacent to the mid left thigh of the dummy. Belt tension T5 acts on this anchor point.

Table 2.
Estimated forces acting on Lifebelt anchorage points, during worst case loading scenario Test 5 D1-4259.

Anchor point	Belt tensions	Belt tensions resolved to component forces			Anchorage force (kN)
		Fx (kN)	Fy (kN)	Fz (kN)	
SG	T1 & T2	9.01	4.36	-16.48	19.28
ELR	T1	0	0	11.28	11.28
OBA	T3 & T4	19.15	6.67	6.97	21.44
OB	T4 & T5	-10.60	11.28	-3.86	15.95
IB	T2 & T3	16.65	-10.60	9.91	22.08
IBA	T5	0	-11.28	0	11.28

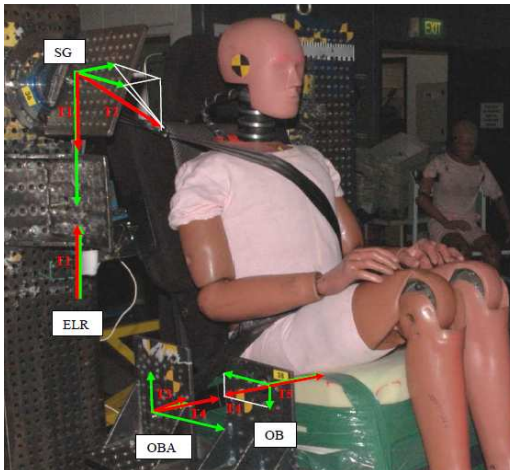

Figure 17. Forces acting on Lifebelt outboard anchor points. The red arrows indicate the applied loads due to belt tension and the green arrows the resultant force on the anchorage point in the local axis system.

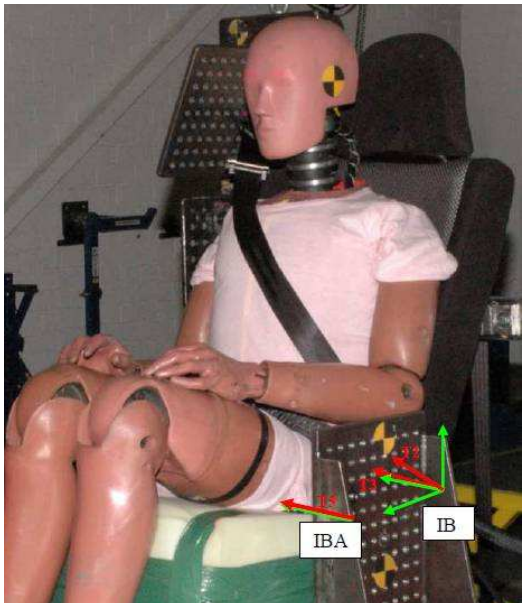

Figure 18. Forces acting on Lifebelt inboard anchor points. The red arrows indicate the applied loads due to belt tension and the green arrows the resultant force on the anchorage points in the local axis system.

The following assumptions were required to estimate loadings at each anchorage point:

- The D rings are frictionless;
- The belt system acts as a cable with uniform tension throughout, i.e. that T1, T2, T3, T4, T5 are equal;
- The belt forces on each D ring act in line with the belt webbing;
- Forces were estimated with the 3D geometry of belt as seen at the maximum excursion of the head of the dummy;
- Maximum excursion was assumed to occur at the same time (t=0.071 s for D1-4259) as the recorded peak sash belt load
- The maximum belt tension was 11.28kN, therefore it was assumed: T1=T2=T3=T4=T5= 11.28kN.

The forces estimated for the D rings and anchorage points are shown in Table 2. In Figures 17 and 18, the red arrows (T1 to T5) indicate the applied loads due to the belt tension and the green arrows the resultant force on the anchorage in the local axis system.

SUMMARY

A new development of the traditional seat belt system has undergone proof of concept testing. The testing of the Lifebelt Seatbelt system presented here clearly demonstrates that it is an effective restraint system for both front and rear seat occupants.

The Lifebelt is able to be used with a simple soft foam seat base design without submarining.

The system makes use of existing seat belt components. To a user there is no change in the operation of the seat belt.

Throughout the tests reported here, the motion of the dummies was well controlled and both the HIII 5F and 50M dummies remained stable and with acceptable biomechanical responses when tested in the Lifebelt.

The high chest deflection readings noted for the tests with both the standard and the Lifebelt systems were able to be dealt with by means of load limiters. The introduction of the load limiters reduced the chest load to acceptable levels and had no negative effects with respect to dummy stability, submarining and other biomechanical responses.

LIMITATIONS

A limitation of the study was that it was based on early developmental systems and was intended to prove the concept only. The results obtained indicate that the enhanced belt system is worthy of further development.

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APPENDIX A

Standard Seat and Seatbelt Control Test - Peak Responses

Parameter	Unit	Control Test 1 (S090258) max / min	Control Test 2 (D1-4260) max / min	Control Test 3 (D1-4306) max/min	IARV	IARV
Dummy		**HIII 5F**	**HIII 5F**	**HIII 50M**	**HIII 5F**	**HIII 50M**
resultant head acceleration	G	78.8	72.7	81.1	193	180
HIC15			598	699	779	700
upper neck force FX	kN	0.1/-1.7	0.0/-1.22	0.01/-1.57	1.9	3.1
upper neck force FY	kN	0.4/-0.3	0.51/-0.10	0.41/-0.14	1.9	3.1
upper neck force FZ	kN	2.7/-0.3	2.54/-0.03	3.66/-0.03	2.07	3.29
upper neck moment MY	Nm	60.0/-34.8	58.7/-39.4	114/-35.3	95 (flexion) 39 (extension)	190 (flexion) 77 (extension)
resultant chest acceleration (3ms)	G		52.4	50.7	73	60
chest compression	mm	-51.0	-56	-55	41	50
viscous criteria	V.C		-0.39	0.49/-0.26	1.0	1.0
upper sternum deflection rate	m/s		0.78/-3.59		8.2	8.2
lower sternum deflection rate	m/s		0.57/-3.59		8.2	8.2
femur force left FZ	kN	2.8/-0.6	2.0/-0.25	2.5/-0.31	6.19	9.07
femur force right FZ	kN	3.0/-1.1	1.49*/-2.27	2.24/-0.16	6.19	9.07
resultant pelvis acceleration (3ms)	G		55.4	58.7		
shoulder belt force	kN	6.6/-0.1	8.41	10.53		
head excursion x	mm		502.6	437.5		
knee excursion x	mm		155.7	63.6		
head excursion z	mm		219.4	318.8		
knee excursion z	mm		51.9	15.6		

Note: the peak dummy response values marked in red equal or exceed the corresponding IARV.

APPENDIX B

HIII 5F Tests - Peak Responses

Parameter	Unit	Lifebelt 1 (D1-4189) max / min	Lifebelt 2 (D1-4258) max / min	Lifebelt 3 (D1-4309) max / min	Lifebelt 4 (D1-4411) max / min	IARV
Dummy		HIII 5F	HIII 5F	HIII 5F	HIII 5F	HIII 5F
resultant head acceleration	g	65.8	60.9	67.7	70.0	193
HIC15		423	367	511	467	779
upper neck force FX	kN	0.16/-1.15	0 /-1.04	0.01/-1.18	0.01/-1.08	1.9
upper neck force FY	kN	0.31/-0.02	0.28/-0.07	0.08/-0.11	0.15/-0.14	1.9
upper neck force FZ	kN	2.31/-0.02	2.08/-0.02	2.32/-0.03	2.42/-0.08	2.07
upper neck moment MY	Nm	61.2/-31.4	49.3/-32.3	44.4/-22.8	50.5/-21.2	95 (flexion)/ 39(extension)
resultant chest acceleration (3ms)	g	53.5	53.8	39.7	40.0	73
chest compression	mm	-55.5	-57	-39	-39	-41
viscous criteria	V.C	0.75	0.8/-0.3	0.64/-0.18	0.65/-0.17	1.0
upper sternum deflection rate	m/s		1.37/-3.73	0.37/-4.23	0.35/-3.93	8.2
lower sternum deflection rate	m/s		1.36 /-3.49	0.61/-3.32	0.29/-3.36	8.2
femur force left FZ	kN	2.09/-0.30	1.79 /-0.68	1.79/-0.32	1.99/-0.34	6.19
femur force right FZ	kN	2.51/-1.41	0.77 /-3.45*	2.73*/-1.17	2.29/-4.15*	6.19
resultant pelvis acceleration (3ms)	G	65	56.2	55.3	59.7	
Left Iliac force	kN				4.09	
Right iliac force	kN				2.64	
Left iliac moment	Nm				34.9/-5.0	
Right iliac moment	Nm				6.2/-26.5	
shoulder belt force	kN		9.22	5.21	5.1^	
head excursion x	mm	278.4	389	490.9	468	
knee excursion x	mm	181.8	167	135.5	138.3	
head excursion z	mm	65.4	102.6	144.6	138.3	
knee excursion z	mm	0	40.6	36.2	37.2	

Note: the peak dummy response values marked in red equal or exceed the corresponding IARV.
* noisy sensor
^ Damaged load cell

APPENDIX C

HIII 50M Tests - Peak Responses

Parameter	Unit	Lifebelt 5 (D1-4259) max/min	Lifebelt 6 (D1-4307) max/min	IARV
Dummy		**HIII 50M**	**HIII 50M**	**HIII 50M**
resultant head acceleration	g	69.3	58.1	180
HIC15		446	294	700
upper neck force FX	kN	0.06/-1.78	0.0/-1.16	3.1
upper neck force FY	kN	0.25/-0.11	0.13/-0.23	3.1
upper neck force FZ	kN	2.55/-0.02	2.3/-0.01	3.29
upper neck moment MY	Nm	120.6/-34.4	78.1/-37.9	190 (flexion) 77 (extension)
resultant chest acceleration (3ms)	g	45.1	46.6	60
chest compression	mm	-61	-52	-50
viscous criteria	V.C	0.47/-0.28	0.56/-0.26	1.0
femur force left FZ	kN	2.31/-0.79	2.67/-0.39	9.07
femur force right FZ	kN	2.65/-0.72	3.25/-0.41	9.07
resultant pelvis acceleration (3ms)	G	49.2	61.6	
shoulder belt force	kN	11.28	5.39	
head excursion x	mm	489.2	475	
knee excursion x	mm	243.4	220	
head excursion z	mm	241	128.1	
knee excursion z	mm	21.5	37.5	

Note: the peak dummy response values marked in red exceed the corresponding IARV.