The Dynamic Rollover Protection (DROP) Research Program

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Abstract - The Dynamic Rollover Protection (DROP) research program is attempting to establish which combination of crash severity, roll kinematics, biomechanical injury criteria, crash test dummy, and restraint systems, address the major proportion of fatalities and serious injuries occurring to seat belted and restrained occupants involved in rollover crashes. The outcomes of this three to four year research program will be an understanding of those factors most important for regulators, industry and consumer groups to consider when developing a dynamic rollover crashworthiness compliance or consumer rating crash test protocol. The research program and progress on the sub tasks from the DROP program are presented. In particular, investigations of how head, chest or thorax fatal injuries are to be replicated for a typical rollover crash, are outlined. The advanced UNSW version of the Jordan Rollover System, recently installed at Sydney's Roads and Maritime Services Crashlab test facility, is also described in the paper.

Keywords: Roll over; Roof crush; Injuries; Crashworthiness; Dynamic rollover test; Jordan Rollover System

INTRODUCTION

Slightly more than half of the fatalities in passenger cars occurring on Australian roads are single vehicle crashes. Of these, one in every three to four occupants killed in a vehicle are in a vehicle that rolls over. Moreover, Australian rollover crashes account for: 12% of all Australian road fatalities; around 35% of all occupant fatalities occurring in a single vehicle crash injury event; around 17% of Australian spinal injuries; and are now greater in number than fatalities occurring in frontal or side impact vehicle crashes [13, 34]. In the USA, one in every three occupant lives are lost in vehicle rollover crashes whereas in Europe around 10% of road users are killed in such crashes.

Despite a very high seatbelt use rate by Australians of around 95% to 97% [12, 31], around 60% of occupants killed were not wearing a seat belt. Furthermore, Fréchède et al [13] found that around 83% of rollover crashes that occurred in Australia were two or less full rollovers (eight ¼ turns). Digges and Eigen [11] also found around 90% of seriously injured non-ejected seat belted occupants occurred in two full rolls or less.

A number of studies to date have also found a positive relationship between the amount of roof crush and the likelihood of serious injury in rollover crashes [1, 8, 9, 18, 20, 26, 30, 34, 35]. However, the forty year debate on this issue still continues to this day. For example, Funk et al, Moffat and Padmanaban, Padmanaban et al, [17, 25, 27] and others continue to state that there is no significant relationship between vehicle roof strength and injuries occurring in rollover crashes. Moreover, recent studies by Bambach et al, Mattos et al and Funk et al [5,17, 24] of contained and restrained occupants involved in single vehicle pure rollover crashes that occurred in the United States indicate that serious injuries to the thorax, head and spine occur even when there is little or no roof crush albeit in significantly reduced proportions.

While a strong roof with an SWR[1] of 4 or more reduces the risk to almost zero in terms of a seat belted occupant being killed in a typical 2 roll or less pure rollover trip crash, serious injuries can still occur [34]. It is not entirely clear how these injuries arise but they appear to be occurring from some form of inertia loading. So far, replicating the real world injuries both in simulations and crash tests has been sporadic and inconsistent [6]. Batzer [6] discusses some of the issues recently concerning observation frequency and relationship to real world crashes for different rollover test rigs.

The Dynamic Rollover Protection (DROP) research program, funded by the Australian Research Council via an industry linkage partnership, is attempting to establish which combination of vehicle rollover crash severity, roll kinematics, biomechanical injury criteria, and crash test dummy, best replicate the major proportion of rollover fatalities and serious injuries occurring to seat belted and restrained occupants in a typical 2 roll or less pure rollover trip crash. The project industry partner organisations include BHP Billiton, Centre for Road Safety at Transport for NSW, the Transport Accident Commission, the Office of Road Safety at Main Road Western Australia and the US Center for Injury Research. The research centres involved are TARS UNSW, Dept. of Civil Engineering at Monash University, Neuroscience Research Laboratories at the Medical College of Wisconsin, BAARG at University of Bolton, NCAC at George Washington University, and School of Biomedical Engineering and Sciences at Virginia Tech (Figure 3).

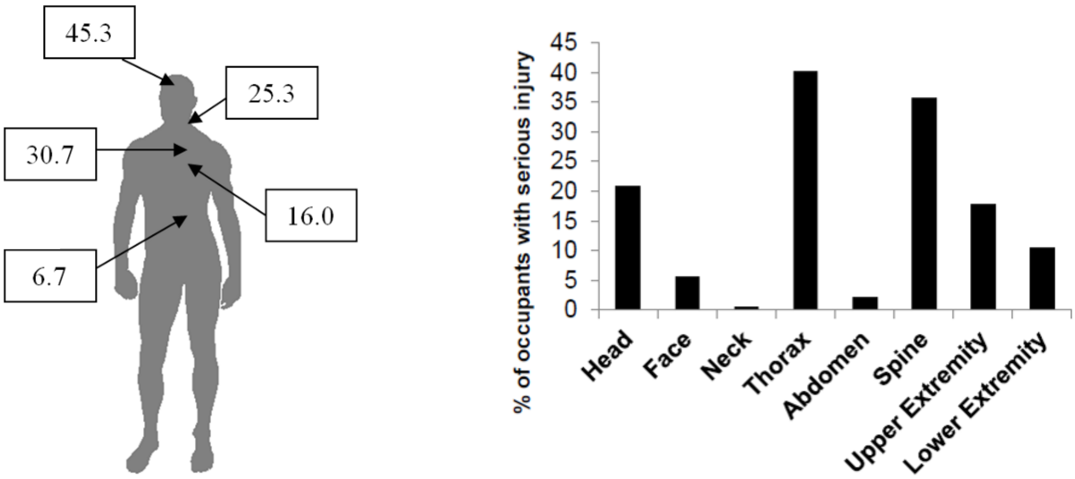
The outcomes of this three year research program will be an understanding of those factors most important for regulators, industry and consumer groups to consider when developing a dynamic rollover crashworthiness compliance or consumer rating crash test protocol. The DROP team will then determine which vehicle components (roof strength, roof geometry, restraint systems, air curtains, etc.), or combination thereof, provide the most effective, practical, and cost efficient rollover injury mitigation strategies for regulators, industry and consumers to consider and adopt.

This paper presents the research program and progress on some of the sub tasks from the DROP program. In particular, investigations of how head, chest or thorax fatal injuries that occur to restrained and contained occupants are to be replicated for a reasonable severity rollover crash, will be outlined. The advanced UNSW version of the Jordan Rollover System (JRS), recently built and installed at Sydney Roads and Maritime Services Crashlab test facility will also be described in the paper. The JRS can carry out rollover crash tests for parametric studies where different aspects of the roll event can be precisely isolated and the results compared to analysis and computer simulations.

TAXONOMY OF ROLLOVER INJURIES

Figure 1 shows results of recent studies by Fréchède et al [13] of Australian National Coroners System fatality data, and Bambach et al [5] and Mattos et al [24] of US National Accident Sampling System – Crashworthiness Data System (NASS-CDS) serious injury data of contained and restrained occupants involved in single vehicle pure rollover crashes. The injury distributions indicate that the serious head, neck/spine and thorax injuries appear to be distributed in roughly 1/3rd proportions. Furthermore, Mattos et al [24] have determined from their study of AIS 3+ injuries in NASS-CDS data over the period of 2000 to 2010 that the majority of serious head injuries (SHI) appear to occur independently to serious thorax injuries (STI) and serious spine injuries (SSI). Figure 2 indicates that around seventy per cent of the occupants with SHI had neither a serious spine nor serious thorax injury. Similar proportions exist for STI and SSI injuries. The fact that head and neck injuries usually

[1] The strength to weight ratio (SWR) is the load measured at 127 mm (five inches) of roof crush divided by the kerb weight of the vehicle during a one-sided quasi static roof crush test. The crush test is carried out using a rigid flat platen 762 mm (thirty inches) wide and 1829 mm (seventy- two inches) long applied to the vehicle front A-pillar at a pitch angle of 5º and roll angle of 25º



Cause of death
Australian NCIS data
(after Fréchède et al [13])

US NASS serious injury data
(after Mattos et al [24])

Figure 1. Seat belted and contained occupants in single vehicle rollover crashes

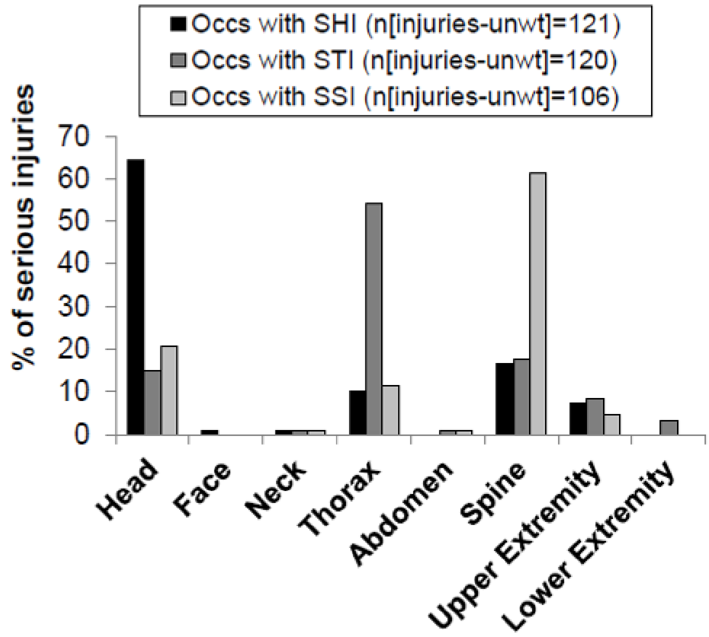


Figure 2: Distribution of occupants with serious injuries AIS 3+ by body region for contained, restrained occupants greater than 16 years old in pure, trip-over rollovers (after Mattos et al [24]).

occur independently of one another and possibly have different mechanisms, was first noted by Friedman and Friedman [14] in 1998 and then confirmed by Atkinson et al. [1], Hu et al. [21] and more recently by Funk et al [17].

DROP RESEARCH PROGRAM

The Dynamic Rollover Protection (DROP) research program was developed as a result of successful research grant submitted to the Australian federal government's Australian Research Council's

Figure 3: DROP research collaborative – February 2012, Sydney, Australia

(left to right: Pof. Ken Digges, Keith Simmons, Prof. Steve Kan, Prof. Clay Gabler, Prof. Clive Chirwa, A/Prof. Andrew McIntosh, Susie Bozzini, Prof. Frank Pintar, Ross Dal Nevo, Prof. Raphael Grzebieta, Dr. Jacqueline Paver, Garrett Mattos, Samantha Collins, Jessica Truong, Dr. Roger Zou, Dr. Mike Bambach, A/Prof. George Rechnitzer, Josh Jimenez – others who participated not in photo: Collin Jackson, Michael Paine, Declan Patton - others who participated via internet: Mike Beebe, Thomas Belcher, Ian Cameron, Don Friedman, Prof. B.K. Han, EunDok Lee, Cindy Shipp, Fadi Tahan, Jerry Wang)

(ARC) Linkage Project grants scheme (No: LP110100069). The first meeting of the research team, partner investigators and partner organisation representatives was held in February 2012 (Figure 3). Presentations from various members of the DROP project team collaborators provided the core research team with an overview of research priorities and direction. On this basis the DROP program research has now focussed on replicating each of the thorax, head and spinal injuries observed in real word data as separate sub-tasks. Figure 4 shows a flow diagram of the process. The intention is to determine and replicate using finite element simulation, how the injuries occur in vehicles, then asses via this computer simulation how the JRS can be adapted and which Anthropomorphic Crash Test Dummies (ATDs) can be used, to apply the biomechanical impact loads that cause the injuries. Some simulation issues in terms of the behaviour of the Hybrid III crash test dummy have already been identified [28]. Biomechanical ATD and cadaver test will be carried out if required to address research gaps.

The starting point of the analyses is that all occupants are assumed to be abiding by the law in accordance with the safe system principles [3], wearing a seat belt, travelling within the speed limit, and through no fault of their own are suddenly involved in a crash (e.g. swerving away from an errant oncoming vehicle). It follows that the law abiding driver (and other occupants in that vehicle) wearing an appropriately fitted restraint, should not die or be seriously injured as a result of the crash event. Presently manufacturers have not been able to ensure this in rollover crashes of reasonable severity, i.e. two or less rolls only on a flat surface, mainly as a result of all the uncertainties in regards to injury mechanisms.

The second starting point for the DROP research program is to assume the vehicle’s roof is strong with an SWR that is rated ‘good’ by the US Insurance Institute of Highway Safety [22], i.e. SWR is equal to or greater than 4. Roof strength plays an essential part in the rollover crashworthiness design of vehicles. Limiting intrusion into the occupant compartment during a crash is critical in order to provide sufficient space for the occupant restraint systems to function and assist with occupant ride down decelerations. Analyses to date indicate when the roof structure is strong and the occupants are restrained by a three point seat belt, deaths and a large majority of the injuries in single vehicle rollover crashes are eliminated [8, 9, 34]. To mitigate those injuries which occur when the roof is

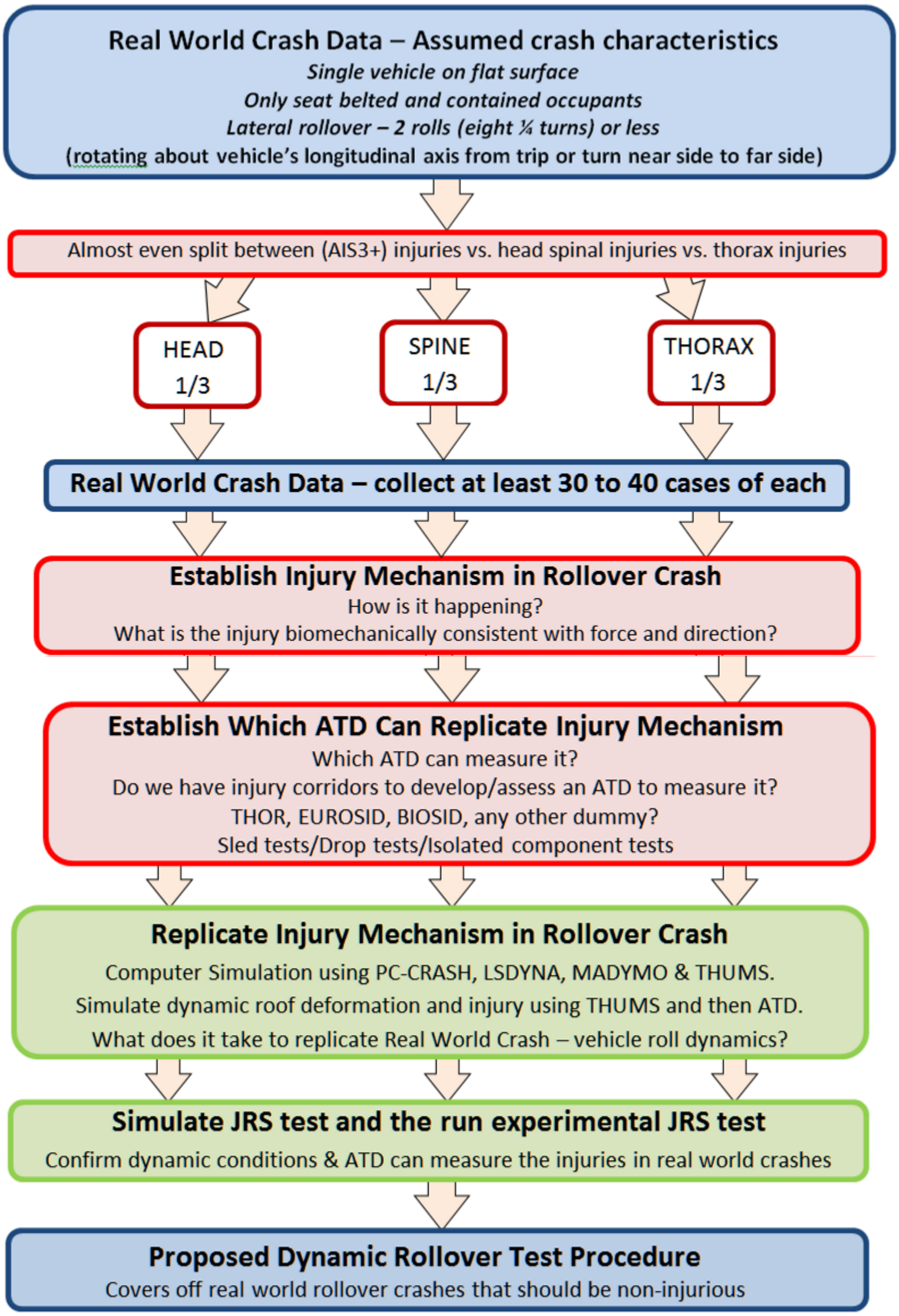


Figure 4: Dynamic Rollover Protection (DROP) program

strong in a reasonable severity two roll or less crash on level ground, the team will start from a position where there is no obvious roof deformation as a proxy that roof crush was not causal to the injuries imparted to the occupants.

Replicating injuries that occur in strong roof vehicles presents a considerable challenge to the DROP researchers. None of the tests carried out to date in either the JRS or the Malibu II test series reported by Freidman and Grzebieta [15] and Bahling et al [4] have generated the accelerations of a magnitude that would indicate potential injuries as observed in some real world cases in terms of head and thorax injuries where there is little or no roof crush above the occupant. For example, to assess if the Hybrid III crash test dummies are capable of replicating injuries from real world rollover cases in simulated dynamic rollover crash tests, thirty-three head impacts, 15 for the near and 18 for the far side Hybrid III test dummies, were analysed from the Malibu II data FMVSS 208 dolly rollover tests and 26 impacts were analysed in the US Center for Injury Research (CFIR) JRS series of tests [23] for all cases of roof deformation. Analysis of the data found no head impacts exceeding a HIC_{36} = 1000 or any chest impacts exceeding 60g that represented the observed injury patterns in the real world [4, 15]. Thus it appears the current test protocols using the FMVSS 208 dolly rollover test and the CFIR JRS and Hybrid III crash tests dummies have not been capable of consistently measuring observed real world head and thorax injuries. Batzer [6] provides some arguments as to why this may be occurring. However, the main issue is that any dynamic testing using the JRS and Hybrid III crash test dummy adopting the current test protocols as proposed in Friedman and Grzebieta [14], will likely not be capable of replicating the injuries identified in strong roof vehicles [34]. Thus a new test protocol must be developed that is more representative of real world crashes where injuries occur.

It is worth noting that papers reporting on the Controlled Impact Rollover System (CRIS) indicate the CRIS rig is capable of producing head loads in Anthropomorphic Crash Test Dummies (ATDs) that would be fatal to humans. However, Batzer [6] points out that the super-elevation of the vehicle's centre of gravity by more than a metre by the CRIS is not representative of uncomplicated ground level rollovers. Moreover, the trajectory of the vehicle, stripping of the inside lining, and the pre-positioning of the dummy orientation of the ATD with tethers, and release of the vehicle such that it impacts the roof directly over the occupant, has been tuned to demonstrate a diving injury impact event. Neither the wheels nor side opposite to the impact side contact the ground when the vehicle is released. As a result, the input to the head and neck of the dummy is very large and when viewed in totality appears unrealistic [6, 10]. Nevertheless, Friedman and Hutchinson have shown that the same loading can be replicated using the JRS [16]. It thus appears that the rollover kinematics induced by the test rig attempting to replicate the real world trip event and associated serious injuries is also a critical component to assessing the rollover crashworthiness of a vehicle.

UNSW JRS TEST RIG

Research is currently being undertaken to design dynamic tests and test protocols that would provide a more accurate assessment of a vehicle's occupant safety in a rollover crash [15, 19, 23]. Three versions of the Jordan Rollover System (JRS) are being used at locations around the world (Center for Injury Research (CFIR) in Goleta, CA, USA; University of Virginia in Charlottesville, VA, USA; University of New South Wales/Crashlab in Sydney, NSW, Australia) to study rollover and determine the feasibility of using the JRS to accurately assess a vehicle's ability to protect occupants in the real world.

The first phase of the DROP program was to construct a JRS test rig for use in Australia. Figure 5 shows a scale model and concept sketch of the UNSW JRS during the design phase developed by Acen Jordan and Don Friedman. The constructed UNSW JRS is shown assembled at the Crashlab facility at Huntingwood near Sydney, in Figure 6. Construction of the rig was funded through another Australian Research Council LIEF Infrastructure grant project scheme (No: LE0989476) submitted in the year prior to the ARC Linkage DROP project application. Monash University and Industry Partner Organisations also provide funding, namely, the New South Wales (NSW) state government's Centre for Road Safety at Transport for NSW (formerly the Roads and Traffic Authority – RTA), the NSW state government's 3rd party insurer Motor Accident Authority (MAA), the West Australian (WA) state government's Office of Road Safety at Main Roads WA, and the US Center for Injury Research (CFIR).

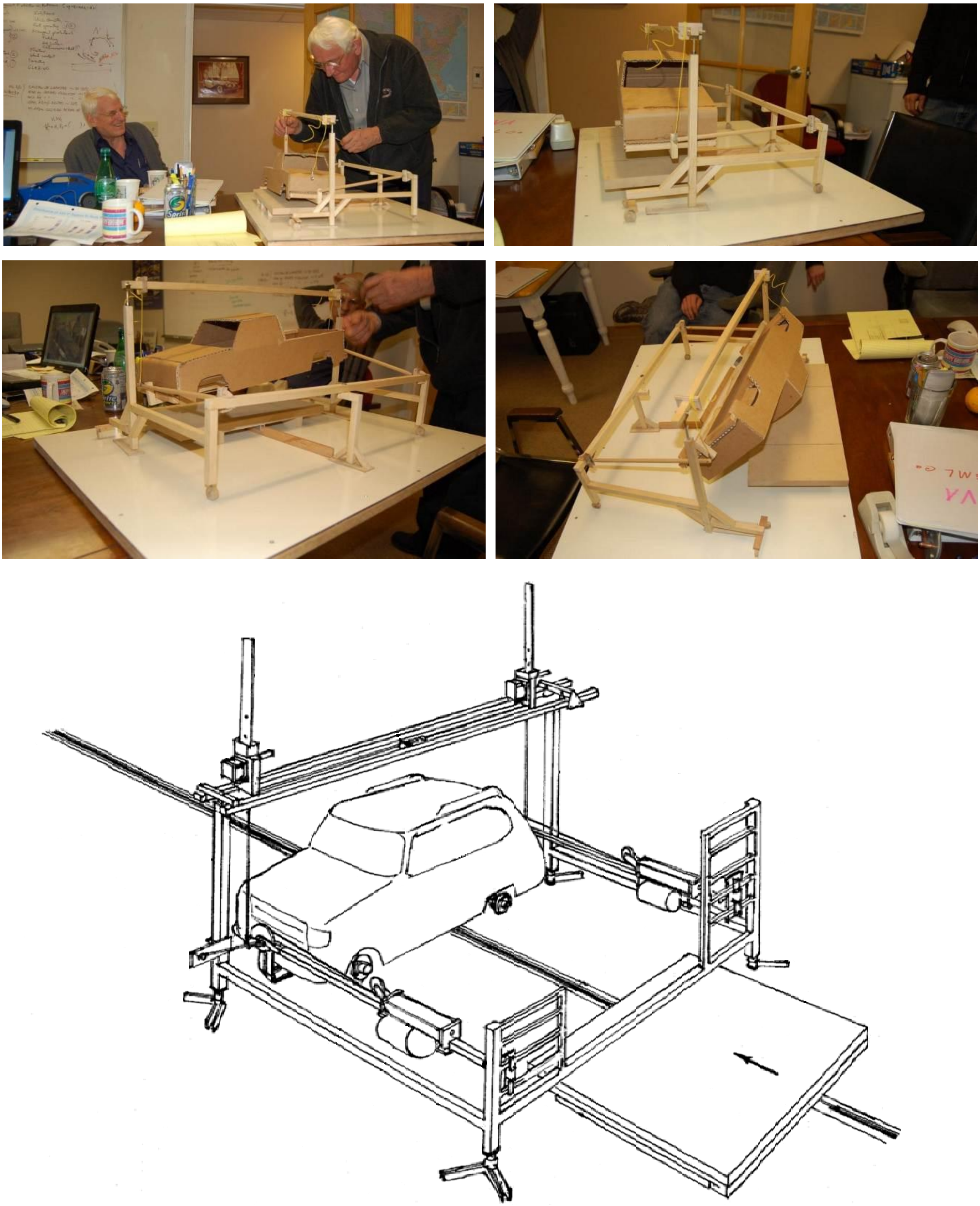


Figure 5: Top: Concept model of UNSW JRS rig.
(Left top frame Carl Nash (on left) and Acen Jordon (on right))

The first author worked closely with the US developers Safety Testing International, who designed and manufactured the rig, to ensure maximum flexibility of the rigs' capabilities so as to address the issues presented and discussed in this paper. The functionality of the UNSW JRS is different to

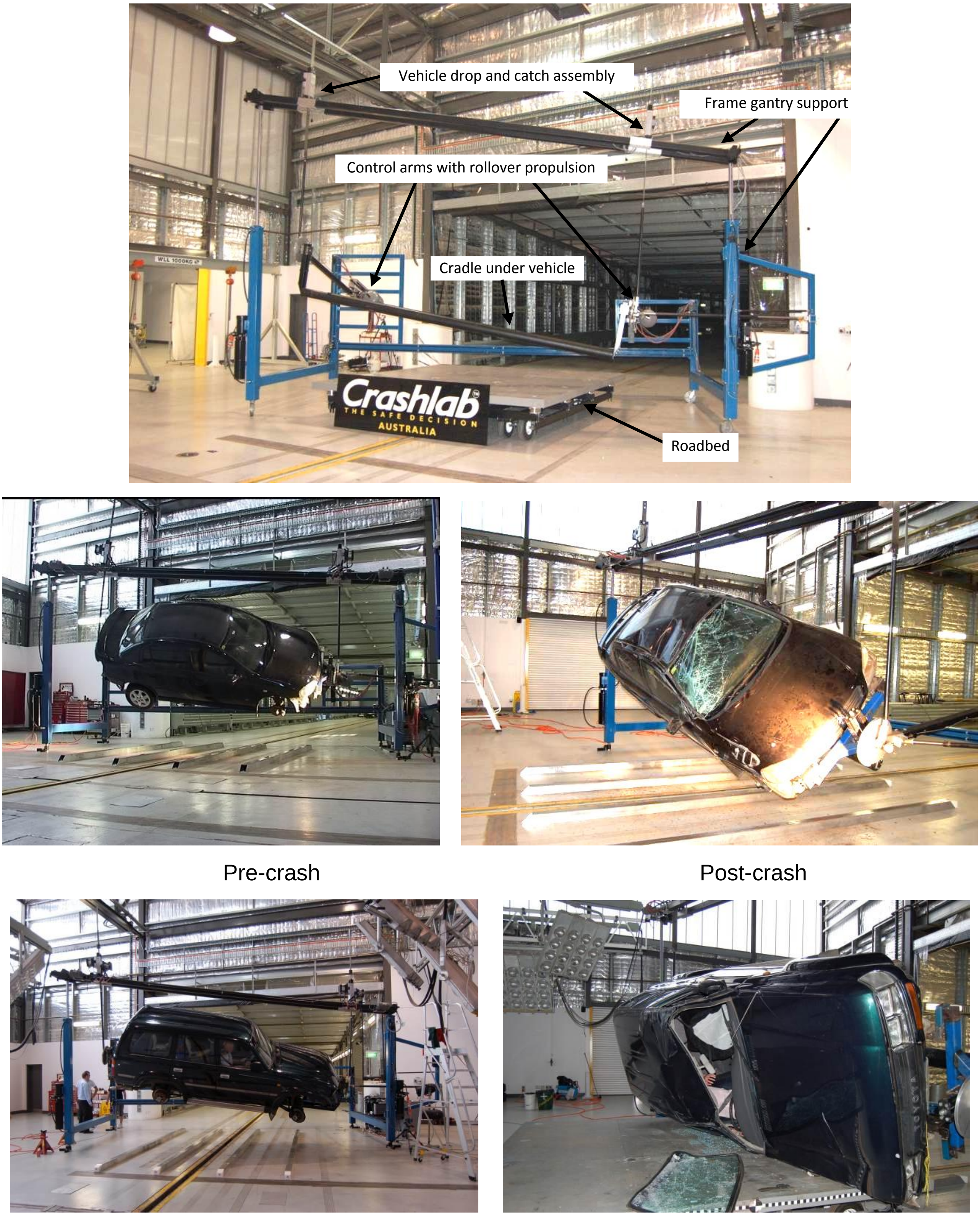


Figure 6: Top: UNSW Jordan Rollover System. Middle: GM Holden Astra. Bottom: Toyota Land Cruiser. Both vehicles tested at 5°pitch, 185deg/sec, 27km/h roadbed speed, and 10° yaw.

the original CFIR JRS [15] in so far that the roadbed works independently of the roll actuator and the vehicle can be set to as much as 30 degrees yaw and 15 degrees pitch. The CFIR JRS roll actuator is linked via a cable to the roadbed and the pitch and yaw capacity are less. Moreover, the CFIR JRS rig continues to pull the roadbed through the test while the vehicle is impacting the roadbed whereas the UNSW JRS releases the roadbed just prior to impact.

Figure 6 shows the UNSW JRS suspends the vehicle via the cradle which in turn is suspended by the drop and catch assembly supported by the frame gantry. The vehicle is free to spin about its longitudinal axis above the track independent of the roadbed which is towed by the Crashlab drive system. The control arms restrain the vehicle in the direction of the roadbed movement but allow vertical movement. The roadbed is instrumented with load cells so that impact load can be measured. The vehicle can be positioned with a predetermined pitch, yaw, and drop height. The terms near and far are used to describe the side of the vehicle that impacts the roadbed first and last, respectively.

At the start of the test, when the roadbed is approaching close to the rig, the roll propulsion unit is activated such that the near side of the vehicle (side opposite to the roof damage evident in the Astra and the Landcruiser in Figure 6) is rotated at a prescribed angular velocity and impacts the moving roadbed at the designated roll angle and pitch. The catch assembly and roll propulsion control arm releases the vehicle so that it can freely rotate and move vertically. Pitch can vary from the initial setting during the roll. At the same time the control arm activates the roll the tow system releases the roadbed just prior to impact. The vehicle then strikes the roadbed on the near side. Skate rails support the roadbed during the impact albeit the roadbed can skate freely through on the support rails as the vehicle continues to rotate on top of it, impacting the far side. Immediately after the road bed passes, the brakes on the catch assembly activate suspending the vehicle above the road way. The road bed is then slowly stopped down the track away from the suspended vehicle. So far three vehicles have been tested in the UNSW JRS, the Holden Astra and the Landcruiser shown in Figures 6. Figure 7 shows two more views of the 1998 Toyota Land Cruiser. Its performance would be rated poor compared to other vehicles that have undergone a similar crash test [15].

Figure 7: Damage profile of the 1998 Toyota Land Cruiser after one roll.

Another issue regarding trying to replicate head and thorax injuries that typically occur in real world crashes concern the use of Hybrid III test dummies in dynamic rollover tests to assess potential injury risk. Paver et al [28] have also indicated issues concerning the Hybrid III's overly stiff neck. Anecdotal evidence indicates that the ATD must be capable of articulating the shoulders relative to the lower torso and hip and the neck may need to be more flexible than the current Hybrid III's neck flexibility. This motion is demonstrated in a rollover crash purportedly of a Volvo vehicle just outside Warsaw Poland that was caught on video and posted on YouTube (Figure 8).

The frames shown in Figure 8 were taken from an interior video within the Volvo of what appears as a pure trip only rollover consisting of 4 quarter turns. The video camera was mounted on the middle dash board facing the driver. The video starts with the vehicle being driven down a straight road. The event begins when the driver swerves and puts the vehicle into a clockwise yaw (A). He then over corrects and the vehicle moves into a counter clockwise yaw (B). The difference in head position between (A) and (B) is worth noting. The driver maintains visual contact of the approaching road on the near side of the vehicle. Also note that the passenger has taken hold of the steering wheel. In (C) we see the vehicle at around 1 quarter turn. The passenger is still gripping the steering wheel. The driver, who is the far side occupant, is being forced towards the window likely as a result of inertial centrifugal force and would have been ejected if not wearing a seat belt and the window was open. The sash part of the seat belt starts to compress into the shoulder. The driver also continues to maintain visual contact with the approaching road through the near side window. In (D) it appears that the angular acceleration of the vehicle has completely overcome the occupant's musculature response. The inertia centrifugal force coupled with the opposing force of the seat belt sash restraining the occupant's left shoulder in the vehicle causes his torso, shoulders and head to be tilted towards the window and B-pillar and away from the approaching road. The centrifugal force is so great against the belt restraining the left shoulder that the driver's shoulders are now parallel to the B-pillar. The inboard side of the driver's head is exposed to the roof rail. The seat belt is applying pressure to driver's shoulder and likely the clavicle and the shoulders appear to be tilted parallel to the B-pillar. The pressure applied to the drivers shoulder is evidenced by the embedment of the seat belt into the driver's muscles and tissue. In (E) we see the driver's head just before it makes contact with the roof rail at approximately 170 degrees of roll. The driver's shoulders are still tilted in line with the B-pillar. The inboard side of the driver's head makes contact with the roof rail in (F). Note the compression of the seat belt into the shoulder and torso.

It also worth noting this compression of the seat belt acting on the driver's shoulder, resisting the inertial centrifugal force, is also likely the force causing clavicle fractures, chest compression with associated outboard rib fractures and possibly lower lumber spinal injuries in occupants that suffer a torso injury in more severe rollovers. Such injuries have been observed by Bambach et al [5] where they state: "*40% of individuals that received serious thoracic injuries from door impacts in pure rollovers, also received injury to the shoulder region on the same side as the thorax injury. These included shoulder contusions (AIS1), clavicle fractures (AIS2), scapula fractures (AIS2) and acromioclavicular joint dislocations (AIS2). Around half of these injuries were attributed to the seatbelt, with the remainder attributed to contacts with the door or B-pillar*."

This anecdotal evidence from the YouTube video indicates that in order for an ATD to appropriately replicate serious head, thorax and spinal injuries, it will likely require a flexible spine that allows the shoulders to dip and articulate in the manner as observed in Figure 6. With the recent advances and activity in Naturalistic Driver Studies [29] where drivers are observed by cameras, it may be possible to collect further video evidence of occupants during a rollover crash to establish their interactions with seat belt restraints.

CONCLUSIONS

The following conclusions can be made from the above:

- Latest investigations of US NASS CDC and Australian NCIS data indicate that serious head, thorax and spine injures in the majority appear to occur in roughly equal proportions and that they occur more or less independently of each other in terms of injury mechanisms. This indicates that each injury type can be independently researched to establish how they occur in vehicle rollover crashes of reasonable severity, i.e. two rollovers or less on a reasonably flat terrain. Solutions could be explored such as for example, if the roof is sufficiently strong (SWR = or > 4) and side air-curtains and airbags are made to fire and maintain inflation during a rollover, this could substantially reduce the incidence of both thorax and head injuries. However, this needs to be proven both numerically and experimentally using for example the JRS test rig and a suitably bio-fidelic ATD.

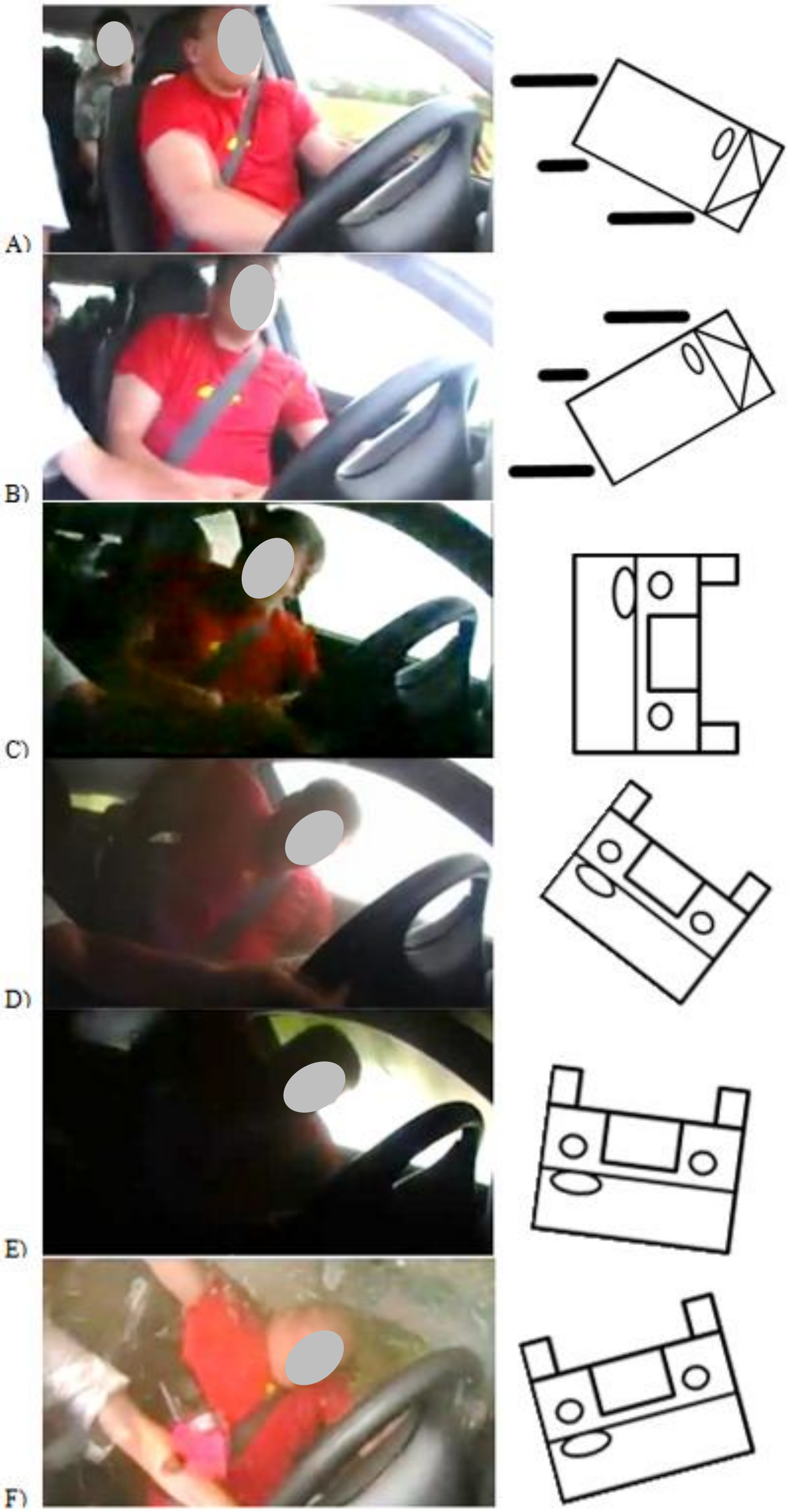


Figure 8: Driver view interior frames from a rollover crash caught on video with figures describing vehicle motion [32].

- To date dynamic rollover crash test rigs, crash test protocols and crash test dummies have not been able to consistently replicate real world serious head, thorax and spinal injuries from in-depth real world crash cases in the same reliable manner as in the case of frontal and side impact crashes. Test rigs based on the JRS and CRIS rigs appear to be capable of repeatable dynamic testing [7, 10, 15, 16] but this still requires further analysis whether the protocols being used reflect real-world crashes. Particularly challenging is the capacity of the new UNSW JRS rig's ability to replicate a crash of sufficient severity that replicates the loading conditions where thorax lung contusions and rib fractures are likely to occur.
- The current Hybrid III ATD is not capable of adequately reflecting the movement and impact responses that result in injuries in reasonable severity rollover crashes considered in this paper. It appears that the ATD must be capable of measuring thorax and head injuries similar in nature to that which occurs in side impact crashes, possesses a clavicle and rib structure capable of measuring forces which indicate fracture risk, and have an articulating spine and less stiff neck which results in shoulder and head movement that is reflective of real world human behaviour. In essence a multi directional crash test dummy will likely be required. Whether the THOR dummy is such an ATD is yet to be ascertained.
- Until such time that the real world injuries observed in strong roof vehicles can be replicated repeatedly in a realistic manner, research on the development of a suitable rollover crash test dummy and appropriate crash test protocol will need to continue.

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REFERENCES

[1] Atkinson, T., Cooper, J., Patel, B., Atkinson, P., (2004). Considerations for rollover simulation, Society of Automotive Engineers, Paper No. 2004-01-0328.

[2] Austin, R., M. Hicks, and S. Summers, (2005). The Role of Post-Crash Headroom in Predicting Roof Contact Injuries to the Head, Neck or Face During FMVSS No.216 Rollovers, DOT, Editor 2005, National Highway Traffic Safety Administration: Washington DC.

[3] Australian Transport Council, (2011). 'National Road Safety Strategy 2011–2020, Canberra.

[4] Bahling, G. S., Bundorf, R. T., Kaspzyk, G. S., Moffatt, E. A., Orlowski, K. F., & Stocke, J. E. (1990). Rollover and drop tests - The influence of roof strength on injury mechanics using belted dummies. SAE Paper No 902314, 1990, Pennsylvania.

[5] Bambach M.R., Grzebieta R.H., McIntosh A.S., (2012) Thoracic injuries to contained and restrained occupants in single-vehicle pure rollover crashes, Accid. Anal. Prev. (In press), http://dx.doi.org/10.1016/j.aap.2012.03.033.

[6] Batzer S. A., (2011). Diving Injury Occurrence in Rollover Collisions: A Critical Analysis of Malibu I, Malibu II and CRIS, Int. J. of Crashworthiness, Taylor & Francis, Vol. 16. No. 2, April, 2011, pp. 219-232.

[7] Bish J., Caplinger J., Friedman D., Jordan A., and Nash C.E., (2005). Repeatability of a Dynamic Rollover Test System, Proc. 19th Int. Tech. Conf. Enhanced Safety Vehicles, Washington, USA

[8] Brumbelow, M.L. and Teoh, E.R. (2009). Roof Strength and Injury Risk in Rollover Crashes of Passenger Cars,Traffic Injury Prevention, 2009. 10 (6): p. 584-592.

[9] Brumbelow, M.L., Teoh E.R., Zuby D.S. and McCartta A.T., (2009). Roof Strength and Injury Risk in Rollover Crashes, Traffic Injury Prevention, 10 (3): p. 252-265.

[10] Chirwa, E. C., Stephenson, R. R., Batzer, S. A., & Grzebieta, R. H. (2010). Review of the Jordan Rollover System (JRS) vis-a-vis other dynamic crash test devices. International Journal of Crashworthiness, 15(5), 553-569.

[11] Digges K and Eigen A., (2003). Crash Attributes that Influence the Severity of Rollover Crashes. Proc. 18th Int. Technical Conference on the Enhanced Safety of Vehicles (ESV), Nagoya, Japan.

[12] Fildes, B., Fitzharris, M., Vulcan,A., Koppel, S., (2004). Benefits of retrofitting seat belt reminder systems to Australian passenger vehicles. Report for the Australian Transport and Safety Bureau: Monash University Accident Research Centre, Melbourne, Australia. Available online: http://www.monashglobal. org/muarc/reports/atsb215.pdf.

[13] Fréchède B., McIntosh A., Grzebieta R.H., Bambach M., (2011). Characteristics of single vehicle rollover fatalities in three Australian states (2000–2007), Accident Analysis & Prevention, Vol. 43, Iss. 3, pp 804-812.

[14] Friedman, D., Friedman, K., (1998). Roof crush versus occupant injury from 1998 to 1992 NASS, Society of Automotive Engineers, Paper No. 980210.

[15] Friedman D. and Grzebieta R.H., (2009). A Proposed Rollover and Comprehensive Rating System, Proc. 21st International Technical Conference on the Enhanced Safety of Vehicles, Stuttgart, Germany, Paper Number 09-0515.

[16] Friedman K. and Hutchinson J., 2008 Review Of Existing Repeatable Vehicle Rollover Dynamic Physical Testing Methods, Proceedings of IMECE2008 ASME International Mechanical Engineering Congress and Exposition, paper no. IMECE2008-68751, Boston, Massachusetts, USA

[17] Funk, J. R., Cormier, J. M., & Manoogian, S. J. (2012). Comparison of risk factors for cervical spine, head, serious, and fatal injury in rollover crashes. Accident Analysis & Prevention, 45 (0), 67-74. doi: 10.1016/j.aap.2011.11.009.

[18] Grzebieta R.H., Bambach M., McIntosh A.S., (2010). How Stronger Roofs Prevent Diving Injuries In Rollover Crashes, Proc. 7th Int. Crashworthiness Conf. ICRASH 2010, ed. Chirwa E.C. and S. Kan, Washington DC.

[19] Grzebieta R., McIntosh A., Bambach M., and Young. D., (2010). Dynamic Test Protocol to Assess Rollover Crashworthiness, Proc. Australasian Road Safety Research, Policing and Education Conference, Canberra, Australia.

[20] Grzebieta R.H., Young D., Bambach M., McIntosh A., (2007). Rollover Crashes: Diving Versus Roof Crush, Proc. 20th International Technical Conference on the Enhanced Safety of Vehicles, Lyon, France, June 2007.

[21] Hu, J., Chou, C.C., Yang, K.H., King, A.I., (2007). A weighted logistic regression analysis for predicting the odds of head/face and neck injuries during rollover crashes, Proc. Assoc. Adv. Automot. Med. 51, 363–379.

[22] Insurance Institute for Highway Safety, (2010). First time Institute rates small pickups for rollover protection; only one model rates good in test that assures strength of roof, News Release, Feb 4, 2010.

http://www.iihs.org/news/rss/pr020410.html and http://www.iihs.org/ratings/roof/information.html

[23] Kerrigan, J., Jordan, A., Parent, D., Zhang, Q. et al., (2011). "Design of a Dynamic Rollover Test System," SAE Int. J. Passeng. Cars – Mech. Syst. 4(1):870-903, 2011, doi:10.4271/2011-01-1116.

[24] Mattos G., Grzebieta R.H., Bambach M., and McIntosh A., (2012). Validation of a Dynamic Rollover Test Device, Proc. Australasian Road Safety Research, Policing and Education Conference, Wellington, New Zealand.

[25] Moffatt E.A. and Padmanaban J., (1995). The relationship between vehicle roof strength and occupant injury in rollover crash data. 39th Annual Proceedings - Association for the Advancement of Automotive Medicine, 1995: p. 245-267.

[26] Mandell, S.P., Kaufman R., Mack C.D., and Bulger E.M., (2010). Mortality and injury patterns associated with roof crush in rollover crashes, Accident Analysis & Prevention, 42 (4): p. 1326-1331.

[27] Padmanaban J., Moffatt E.A., and Marth D.R., (2005). Factors influencing the likelihood of fatality and serious/fatal injury in single-vehicle rollover crashes, New York, NY, ETATS-UNIS: Society of Automotive Engineers.

[28] Paver, J., D. Friedman, F. Carlin, J. Bish, J. Caplinger and D. Rohde, (2008). “Rollover Crash Neck Injury Replication and Injury Potential Assessment.” Proc. International Research Council on Biomechanics of Injury (IRCOBI), Bern Switzerland.

[29] Regan, M.A., Williamson, A., Grzebieta, R, Tao, L., (2012). Naturalistic Driving Studies: Literature Review and Planning for the Australian Naturalistic Driving Study, Proc. Australasian College Of Road Safety Conference, A Safe System: Expanding The Reach, Sydney, August, 2012.

[30] Strashny, A., (2007). The Role of Vertical Roof Intrusion and Post-Crash Headroom in Predicting Roof Contact Injuries to the Head, Neck, or Face During FMVSS No.216 Rollovers; An Updated Analysis, DOT, Editor 2007, National Highway Traffic Safety Administration: Washington DC.

[31] Wundersitz, L. N. and Raferty S.J., (2011). No restraint? Understanding differences in seat belt use between fatal crashes and observational surveys, Centre for Automotive Safety Research, The University of Adelaide, Report No. CASR090, ISBN: 9781921645273. Available online:

http://casr.adelaide.edu.au/casrpubfile/1076/CASR090.pdf

[32] YouTube, (2009). Roll over in a Volvo Retrieved December 2011, from

http://www.youtube.com/watch?v=Gn_xhKTV5lY

[33] Young D., Grzebieta R.H., McIntosh A., Bambach A. & Frechede B., (2007) Diving vs Roof Intrusion: A Review of Rollover Injury Causation, International Journal of Crashworthiness, Vol. 12 No. 6 pp. 609–628.

[34] Young, D., (2010), PhD Thesis, Protecting Occupants During Passenger Vehicle Rollover Crashes, Dept. of Civil Engineering, Monash University.

[35] Young D.P. and Grzebieta R.H., (2010) Vehicle roof strength as it relates to contained occupant injury prevention during rollover crashes, Proc. Australasian Road Safety Research, Policing and Education Conference, Canberra, Australia.