Part 3:

ROLLOVER CRASHWORTHINESS TEST RESULTS

REPORT 3

by

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[1] http://www.dynres.com/

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Disclaimer

The analyses, conclusions and/or opinions presented in this report are those of the Authors and are based on information noted and made available to the Authors at the time of its writing. Further review and analyses may be required should additional information become available, which may affect the analyses, conclusions and/or opinions expressed in this report.

While the project has been widely researched and developed, with much input from many sources worldwide, the research methods, ratings system, conclusions and recommendations are the responsibility of the Authors. Any views expressed are not necessarily those of the funding agencies, the Project Reference Group, FCAI or others who have assisted with this Project.

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1. Executive Summary

This is the third major test report (Part 3: Rollover Crashworthiness Test Results – Report 3) for the Project which is focussed on assessing the Rollover Crashworthiness of the Quad bikes and Side by Side Vehicles (SSVs) for the workplace. This report follows on from Part 1: Static Stability Test Results (Report 1) and Part 2: Dynamic Handling Test Results (Report 2). There is a fourth report (Report 4) which is titled Final Project Summary Report: Quad Bike Performance Project Test Results, Conclusions and Recommendations. There is also a Supplemental Report that presents a summary of the 'Examination and Analysis of Quad Bike and Side By Side Vehicle (SSV) Fatalities and Injuries' carried out by McIntosh and Patton (2014a) and Mitchell (2014) and some further analysis by the co-Authors Grzebieta, Rechnitzer and Simmons.

The Quad Bike Performance Project (QBPP) is aimed at improving the safety of Quad bikes, in the workplace and farm environment by critically evaluating, conducting research, and carrying out testing, to identify the engineering and design features required for improved vehicle Static Stability, Dynamic Handling and Rollover Crashworthiness including operator protective devices and accessories. This is being done through the application of a Quad bike and Side by Side Vehicle Star Rating system (ATVAP: Australian Terrain Vehicle Assessment Program) to inform consumers purchasing vehicles for the workplace and farming environment.

The Rollover Crashworthiness test program provides the third arm of the assessment and Star Rating of Quad bikes and SSVs for the workplace for rollover Static Stability, Dynamic Handling and Rollover Crashworthiness. The Rollover Crashworthiness program complements the Static Stability test program and the Dynamic Handling test program for 17 vehicles (see Figure 1 and Figure 2). Included in the 17 vehicles are 8 production work Quad bikes, 3 recreational Quad bikes, 5 SSVs, and a prototype Quad bike. The reader is referred to Part 1: Static Stability Test Results report for the detailed introduction and background to the Quad Bike Performance Project (QBPP) and ATVAP (also see Rechnitzer et al., 2013), which is not repeated here.

The rollover crashworthiness test program consisted of 65 Quad bike and SSV tests and SSV inspections focussing on four different areas all relating to vehicle rollover crashworthiness characteristics, namely, measurement of ground contact loads; inspection and measurements of SSV occupant retention; vehicle dynamic rollover tests; and SSV ROPS structure load tests. For four wheel vehicles the well accepted means of protection in rollovers (in any direction) is the use of a Rollover Protection System (ROPS), seatbelts, and occupant containment including the prevention of partial or full ejection. SSVs are designed to provide ROPS and Seatbelts and varying degrees of containment. However, for Quad bikes which are 'rider active' vehicles with straddle seats, their current design cannot readily accommodate ROPS, seatbelts, and containment without negating 'Active Riding' operation. Therefore, other rider protection measures for Quad bikes, have been considered, e.g. an Operator Protection Device (OPD). The manufacturer's stated safety strategy for Quad bikes is based on rider separation with some softening of the vehicle's outer surface (except for handle bars and load racks) and to date have rejected the use of OPDs for reasons some of which are discussed in this report.[2]

An in-depth case series study of fatal Australian Quad bike and SSV cases for the period 2000 to 2012 (total 141 cases, with 109 relevant cases) showed that rollover (in any direction) and being pinned, resulting in mechanical asphyxia, are the dominant features of Quad bike related fatalities on farms. Therefore, the focus of crashworthiness tests is rollover in the lateral, forward pitch and rearward pitch directions.

Section 2 of the report provides: background to the test program, which includes some information concerning fatalities and injuries that were the basis for the adopted rollover crashworthiness assessment protocol; the vehicles and OPDs that were tested; the rollover crashworthiness tests undertaken including assessment criteria; a selection of key test results; and, an analysis of the test program.

Section 3 of the report provides the rating methodology, the rating tables and key findings.

Section 4 presents the Conclusions. The significance of the test results to the project and the Quad bike and SSV ratings, as well as the effectiveness of the OPDs is described in section 4.

Attachment 1 is the Crashlab report with Appendices which provides the detailed background, test methods and results on the rollover crashworthiness testing undertaken.

Key findings are:

1. As a result of the rollover testing conducted by the Authors, it became apparent that it is currently unrealistic to discriminate the rollover crashworthiness between different Quad bike models. However, discrimination between vehicle types (i.e., Quad bikes and SSVs) was feasible;
2. It was concluded that the term "Crashworthy Quad bike" is fundamentally a contradiction in terms. Therefore, all Quad bikes were rated equally for rollover crashworthiness and assigned the same 5 points baseline rating for rollover crashworthiness protection;
3. It is not possible at present to discriminate Quad bike crashworthiness performance based on real world crash information (in contrast to passenger vehicles, for example), due to the absence of make/model/year (MMY) crash involvement injury data and exposure data collected for Quad bikes and SSVs. This fundamental deficiency with data collection for Quad bikes (and SSVs) remains an impediment to advancing Quad bike safety. For Quad bikes, given that this vehicle type's rollover resistance is much less than SSVs, rollover crash prevention is the primary control mechanism to prevent injury

[2] This includes both manufacturers and distributors of Quad bikes and Side by Side Vehicles (SSVs). For convenience in this report, where it is noted the Quad bike industry this includes manufacturers and distributors of both Quad bikes and SSVs.

in rollover. The fitment of Operator Protection Devices (OPDs) to Quad bikes is seen by safety stakeholders as an engineering control that may reduce injury risk in some circumstances. However, the industry claim via their own analyses is that OPDs might increase injury risk in some circumstances, although this claim is not supported by any reported Australian cases from real world crash data. As with motorcycles, the safety crashworthiness basis promoted by industry for Quad bikes is separation. Similarly if increased crash protection is a key performance requirement then different vehicle types, e.g. SSVs, which offer such protection as part of their design need to be considered and used instead, in line with choosing 'Fit For Purpose' vehicles within the risk management framework;

4. In contrast to current Quad bike designs, the SSVs do adhere in general to rollover crashworthiness principles, in that they are fitted with ROPS, seatbelts and various degrees of occupant containment measures which combine to keep the occupants within the protected space. The effectiveness of such designs in terms of severe injury prevention can vary widely. It is possible to discriminate and to rate SSV crashworthiness;
5. On balance, the Authors consider that the addition of an OPD will likely result in a net benefit in terms of reducing harm to workplace Quad bike riders involved in a rollover crash. This is based on: (a) the assumption that Quad bike overturns in the workplace environment typically occur at low speeds; (b) the results of limited testing, and (c) the Authors are currently unaware of any injuries from OPDs that have occurred in the field.

   The important qualifiers for OPDs are:

   a. A 'fitness for purpose assessment' be carried out first and the opportunity to substitute a well-designed SSV, for example, for a Quad bike should be considered. If an SSV is not 'Fit For Purpose', then an OPD is an engineering control that may improve Quad bike safety in the workplace.
   b. In some crash events such OPD devices could theoretically result in injury – rather than prevent it[3];
   c. Close monitoring and ongoing evaluation of the field performance of OPDs is essential.
   d. That improved, more in-depth and uniform Quad bike and SSV accident data collection forms and procedures be put in place at state and federal levels, to enable monitoring of the relevant details of Quad bike and SSV incidents, including OPD and ROPS/ seat belt effects (both positive and negative).

[3] The Authors are not aware of any reported injury from an OPD (Quadbar or Lifeguard). However, the Authors are aware of injuries reported from SSV Rollover Protection Systems (ROPS) as a result of operators not using the installed seat belts and being ejected and injured by the ROPS during a rollover crash. Wearing the supplied seat belt (3 point or harness) is critical to ensuring the ROPS provides adequate protection during such an event.

The Rollover Crashworthiness Overall Rating Index

6. The 17 vehicles were assigned a Rollover Crashworthiness Overall Rating Index out of a maximum of 25 points. The rating reflects the Authors' assessment of the rollover crashworthiness of the tested vehicles for the workplace environment. The ratings are based on physical rollover tests, an evaluation against the ANSI/ROHVA standard, and fundamental crashworthiness principles of rider/occupant protection in rollovers. It was noted that:

   a. The SSVs, all have notably higher overall rating (see Table 3 and Figure 15) with rating scores from 15 to 21, with the Tomcar and John Deere receiving the highest rating. These rating scores compare with 5 points awarded to each of the work Quad bikes and recreational Quad bikes;

   b. In regards to the Quad bikes, the maximum Rollover Crashworthiness Overall Rating Index these vehicles can potentially receive is 5 out of 25 if the straddle Position is maintained with respect to the design of the vehicle and no rider protection is fitted to the vehicles, i.e. a ROPS. The work Quad bikes were all index rated at 5 points;

   c. In contrast to the current Quad bike designs, well designed SSVs offer superior rollover crash protection in a typical farming environment, i.e. they are fitted with ROPS, seatbelts and various degrees of containment measures which combine to keep the occupants within a protected space. This does not rule out that Quad bike designs cannot be improved in future to provide similar levels of crashworthiness safety to well designed SSVs. This is provided that three point (or harness) seatbelts, helmets are worn and other occupant lateral restraints are fitted and in place;

   d. The results from the rollover crashworthiness tests provide sufficient discrimination in the range of vehicles tested (Quad bikes and SSVs) to form the basis for the rollover crashworthiness rating system;

   e. The real-world validation and ongoing improvement and refinement of the crashworthiness ratings and Quad bike and SSV safety design, will depend on the ongoing, proper, systematic collection of real world crash data involving Quad bikes and SSVs, including MMY and exposure data.

2. ROLLOVER CRASHWORTHINESS TESTING AND RESULTS

2.1 Introduction to the rollover crashworthiness test program

The Quad Bike Performance Project (QBPP) is aimed at improving the safety of Quad bikes, in the workplace and farm environment by critically evaluating, conducting research, and carrying out testing, to identify the engineering and design features required for improved vehicle stability, dynamic handling and improved crashworthiness including operator protective devices and accessories. This is being done through the application of a Quad bike and Side by Side Vehicle Star Rating system (ATVAP: Australian Terrain Vehicle Assessment Program) to inform consumers purchasing vehicles for the workplace and farming environment.

This is the third major test report for the Quad Bike Performance Project (QBPP), and follows on from Part 1: Static Stability Test Results (Report 1) and Part 2: Dynamic Handling Test Results (Report 2), for the 16 production vehicles, one prototype Quad bike and the operator protective devices (OPDs) tested (see Figure 1 and Figure 2). The objective of the QBPP is to develop an Australian Terrain Vehicle Assessment Program (ATVAP) relative rating system to inform consumers purchasing vehicles for the workplace and farming environment. The reader is referred to the Part 1: Static Stability Test Results report for the detailed introduction and background to the Project and ATVAP (also see Rechnitzer et al., 2013), which is not repeated here.

A series of tests were carried out at the NSW Roads and Maritime Crashlab test laboratory located in Huntingwood, NSW, Australia, to determine the rollover crashworthiness characteristics of the Quad bikes and SSV vehicles. These were intended to provide the basis for the Rollover Crashworthiness Overall Rating Index for each vehicle.

Crashworthiness is defined as the ability of a vehicle to protect an occupant in a particular crash scenario, in this case rollover involving lateral roll, forward pitch or rear pitch. From the review of the Coroners fatalities for Quad bikes, prevention of riders being pinned and suffering crush injuries and mechanical asphyxia in rollovers, were key indicators for the crashworthiness tests and criteria.

The Report Structure

The report is presented in a number of sections:

Section 1 is the Executive Summary and is intentionally brief.

Section 2 of the report provides: the background information which includes some information concerning fatalities and injuries that were the basis for the adopted rollover crashworthiness assessment protocol; the vehicles and OPDs that were tested; the rollover crashworthiness tests undertaken including assessment criteria; and some selected key test results and analyses from the test program.

Section 3 of the report provides the rating methodology, the rating tables and key findings.

Section 4 details the Conclusions where the significance of the test results to the project and the Quad bike and SSV ratings and the effectiveness of the OPDs is provided.

Attachment 1 is the Crashlab report with Appendices which provides the detailed background, test methods and results on the rollover crashworthiness testing undertaken.

Hence, the Report structure is as follows:

SECTION 1: Executive Summary.

SECTION 2: Rollover Crashworthiness Testing and Results

SECTION 3: Rollover Crashworthiness Overall Rating Index for the 16 Production Test Vehicles

SECTION 4: Conclusions

References and Appendix

Attachment 1: Crashlab Special Report SR2014/003, Quad Bike Performance Project Crashworthiness Testing, and Appendices A, B, C, D, E, F.

Appendix A – Test matrix
Appendix B – Instrument response data
Appendix C – Test specimen details
Appendix D – Test photographs
Appendix E – Instrument details

2.2 Quad Bike Fatalities and Injuries in Australia (2000-2012)

Prior to developing the Rollover Crashworthiness tests and ratings, the Authors

The following section summarises the key findings relating to Quad bike deaths and injuries arising from the in-depth case series study of fatal crashes and incidents by McIntosh and Patton (2014a), and the review of Quad bike injury data by Mitchell (2014), for the project.

The overarching conclusion from this data is that rollover and being pinned by the Quad bike are the most frequent characteristics of Quad bike related fatalities on farms.

These findings were used to help determine that the crashworthiness test program needs to be focussed on rollover of the Quad bikes and SSVs, with testing and ratings developed as presented in this report.

In summary, the key findings from the McIntosh and Patton (2014a) study are:

1. 141 fatalities were identified from the Australian National Coronial Information System (NCIS) dataset, i.e. approximately 10 to 15 fatalities per annum;
2. 109 fatal cases were relevant, the other 32 cases involved public road crashes, pillions and other vehicle types;
3. Of the 109 cases there were 106 Quad bikes, and two SSVs and one six wheel bike;

4. 86% of deaths were male;
5. Approximately 50% of the 109 fatalities were related to farming activity and 50% (55) to recreational activity;
6. Approximately 75% of the 109 fatalities occurred on Farms, and the farm fatalities involved a mixture of work and recreational uses;
7. Rollover occurred in 71% of the 109 cases. Of these 85% of the work related fatal cases involved[4] a rollover (whether or not the rollover was related to the fatal injury mechanism) compared to 56% of recreational cases;
8. Lost control on a slope and/or driving over an object was a factor in 58% of the farm cases and 33% of recreational cases;
9. In work related fatal cases, older riders appeared to predominate fatalities, namely: 78% were 50 or older; 50% were 60 years or older; 42% were 65 years or older; and 33% were 70 or older. In comparison, for all fatal cases, 43% were 50 years or older, and only 9% of recreational riders killed were 50 years or older.
10. The main cause of death for farm workers was chest injury (59%) compared to head injury for recreational riders (49%);
11. Around 13% of farm workers died as a result of head injury. A helmet was found to be worn in only 22% of the 109 cases;
12. The dominant injury mechanism for farm cases was rollover followed by being pinned by the vehicle resulting in crush injury and or/ mechanical asphyxia. 69% (37) of the farm workers fatally injured were pinned under the quad bike, and the majority of these suffered crush injury or asphyxia;
13. Almost 50% of the farm work fatalities were caused by mechanical asphyxia, with approximately 77% of these estimated to have been survivable incidents if the rider had not remained pinned;
14. For recreational riders, a smaller percentage was pinned under the Quad bike, at about 33%;
15. Regarding Quad bike & SSV injuries, based on NSW hospital admission and other injury databases, it is estimated that there are approximately 1400 presentations per annum for Australia at hospitals, for minor to severe injuries (Mitchell, 2014);
16. For farm work fatalities where the rider was pinned (37 from 54), 26% (14) had an attachment or accessory such as a spray tank or trailer on the Quad bike and 32% (12

[4] Note that the term "involved a rollover" does not necessarily imply that the fatal injury mechanism was related to rollover. In some cases, for example, the Quad bike may impact an object, the rider may be ejected from the Quad bike and impact a rock, and the Quad bike may subsequently roll over. This type of sequence is still described as "involving a rollover".

of 37) being unknown as to whether any attachments/accessories were present on the Quad bike. The percentage of farmers killed where the vehicle had an attachment of some form was 43% (16 of 54) with 26% (14) unknown.

As noted, rollover was the predominant crash type. Where the roll direction was noted, there were 11 (10.1%) forward rolls, 32 (29.4%) lateral rolls, 5 (4.6%) rearward rolls. In 29 (26.6%) cases rollover was noted but the roll direction was unknown.

The older age of fatal cases on farms, is particularly relevant in so far that the motivation and capacity of older riders to ride a Quad bike 'actively' may be significantly less than a younger rider. In effect, it is possible, and might be expected that some older riders may be more likely to ride the vehicle passively, continuously seated on the seat, and not actively leaning or standing on the Quad bike to influence its stability or control. If this is a valid assumption, then this might suggest that a more appropriate vehicle for this older age group would be SSV style vehicles, which do not require an Active Riding style, and are also designed to a carry loads and a passenger. However, to be effective in terms of rollover crashworthiness, SSVs require the operator to use the seat belts.

Rollover accompanied by crush and asphyxiation was identified by McIntosh and Patton (2014a) as one of the major injury causal mechanisms occurring in farming related crashes. Around 62% of farm workers received crushing injuries under the vehicle, e.g., they received a flail chest. Moreover, fifty-five (50.5%) of the sub-sample of 109 deceased riders were pinned by the Quad bike, i.e. the person was restrained under the vehicle and subject to crushing forces. A higher proportion of farm workers (n=37, 68.5%) were pinned under the Quad bike than recreational riders (n=18, 32.7%). This was the dominant injury mechanism for farm workers and is of particular concern to workplace Work Health and Safety regulators and farmers.

Almost half the farm work fatalities (n=26) were caused by asphyxia or a related condition. In these cases the worker was pinned under the quad bike and typically suffered no injury to a body region other than the thorax and injuries to the thorax were not otherwise fatal. The data suggest strongly that approximately one third (n=20) of the farm workers who died of asphyxia would have survived the crash if the vehicle did not pin them with a force sufficient in terms of magnitude and duration to cause asphyxia. In the other fatal farm work cases a large proportion of those not asphyxiated were injured when the Quad bike interacted with the operator during a rollover.

Fatal and non-fatal Quad bike related injuries were obtained from various data collections including: National Coronial Information System (NCIS) and the associated local jurisdiction case files, Safe Work Australia's National Dataset for Compensation-based Statistics (NDS), WorkCover NSW's workers' compensation scheme claims, WorkCover NSW's incident reports, Transport for NSW's Road Crash Analysis System (RCAS), the NSW Admitted Patient Data Collection (APDC), and the NSW Public Health Real-time Emergency Department Surveillance System (PHREDSS). The data indicates that over a seven year period there were around 3,307 records of Quad/SSV related Emergency Department Presentations (EDP) for NSW (around 472 per year). NSW has a population of around 7.3 million and is around 32% of Australia's total population. Extrapolating the injury count for Quads/SSVs one could expect currently a total of around 1400 EDP for Australia each year.

2.3 The test vehicles and the OPDs

The 17 Test Vehicles

The seventeen vehicles considered for rollover crashworthiness ratings are presented in Figure 1 comprising eight Quad bikes typically used in the work place, particularly on farms; three sports/ recreational type Quad bikes; five Side-by-Side style off-road vehicles used in the workplace/farms, and the prototype Quad bike.

The prototype Quad bike was assessed in order to see what final star rating it would have received compared to all other vehicles. This vehicle has been specifically designed with a modified suspension system that increased its static stability and dynamic handling performance. Details concerning this prototype Quad bike are presented in Part 2: Dynamic Handling Test Results (Report 2).

Operator Protective Devices (OPDs)

The two Operator Protection Devices (OPDs), also known as Crush Protection Devices (CPDs), were assessed in this test series to determine their effect on rollover crashworthiness (see Figure 2). Each of the OPDs was fitted to one of the quad bikes (Honda TRX500) which was then subjected to rollover crash tests. The Honda TRX500 quad bike was selected to represent a typical Quad bike with respect to rollover crashworthiness factors.

At the start of this Part 3 crashworthiness assessment of the Quad bike Performance Program, it was deemed by the Authors that the term "Crashworthy Quad bike" was essentially a contradiction of terms. It was concluded that it is impractical to design a Quad bike where a rider can 'Actively Ride' and at the same time be fully protected by a Rollover Protection System (ROPS) and restraint system.

The Industry position regarding rollover crashes associated with Quad bikes is similar to that often advocated by expert motorcyclists when they advise riders to separate from the vehicle if they lose control of a motorbike and fall to the ground/ roadway. The principle underpinning that advice is one of separation of the rider from the vehicle and maintaining that separation. However such separation is more problematic on a Quad bike due to its higher weight, lower speeds, the wider 4 wheel design compared with the narrow motorcycle body, the crash environment, and motorcycles don't typically rollover onto a rider.

In the case of Quad bikes, the advice from industry design experts is that the vehicle should essentially be rounded and smooth (in the lateral direction) with padding and soft outer parts so that it can readily roll off the rider as presented by Van Ee et al. (2012) in Figure 3.

No.	Model		No.	Model	
1	Honda TRX250; Quad bike ($6k)*		9	Can-am DS90X; Sports/ Rec Quad bike (youth) ($5k)	
2	Honda TRX500FM; Quad bike ($12k)		10	Yamaha YFM250R Raptor; Sports/ Rec Quad bike ($8k)	
3	Yamaha YFM450FAP Grizzly Quad bike ($12k)		11	Honda TRX700XX; Sports Rec Quad bike ($13k)	
4	Polaris Sportsman 450HO; Quad bike ($8k)		12	Yamaha YXR Rhino; SSV ($17k)	
5	Suzuki Kingquad 400ASI; Quad bike ($9k)		13	Kubota RTV500; SSV ($14k)	
6	Kawasaki KVF300; Quad bike ($6k)		14	John Deere XUV825i; SSV ($18k)	
7	Kymco MXU300; Quad bike ($6k)		15	Honda MUV700 Big Red; SSV ($18k)	
8	CF Moto; CF500 Quad bike ($6.5k)		16	Tomcar TM2; SSV ($25k)	
			17	Prototype wide track Quad bike	

*Approximate bulk purchase cost for the project in Australian dollars, 1k=$1,000 (purchased November 2012 including 10% GST). Note: prices will vary depending on where the vehicle is purchased and under what terms.

Figure 1: The 17 Test Vehicles

Quadbar	Lifeguard
QB Industries	Ag TECH industries
8.5kg	14.8kg
	

Figure 2: The OPD unit used in the rollover crash tests with the 'work' Quad bike.

Obstructions fitted to the Quad bike should be minimised so that the rider can separate from or 'jump clear' of the Quad bike in case they lose control, for example, on a turn or on a slope. A rider should be able to separate quickly from the Quad bike without being obstructed for example by an OPD as indicated in Figure 4 by Van Ee et al. (2012) or by spray tanks, etc. In around 46% (½) of the farm fatalities investigated by the Authors attachments (spray tanks and/or trailer) were fitted to the Quad bike. Van Ee et al. (2012) also show in Figures 4 and 5, scenarios in further support of the industry position, of how the rider could potentially be obstructed from separating from under the Quad bike in forward and rearward pitch situations.

Van Ee et al. (2012) also indicated that a Quad bike should not have any protrusions that can potentially impact or stab a rider: that such a scenario may be possible in a forward pitch incident where the rider could potentially be stabbed by for example a Quadbar in the head, neck or back, as presented by them in Figure 4. They further postulate that a vehicle with an OPD such as a Quadbar can potentially act as a lever, causing the vehicle's Centre of Gravity (CG) to be raised to a higher position than a vehicle without an OPD, just before it could potentially crash on top of a rider that may be laying underneath the vehicle as demonstrated in Figure 6.

It is also for these reasons that Quad bikes fitted with OPDs do not satisfy the fundamental crashworthiness criteria for rollover, i.e. containment and crush protection. OPDs can improve rollover crash survivability in some cases, as has been demonstrated in the two-post ROPS program in the case of tractors, but not comprehensively. Nevertheless, these scenarios will be assessed in context of the vehicle and rider/driver rollover tests that were carried out on the Honda TRX500 Quad bike with and without an OPD.

Figure 3: Van Ee et al. (2012) demonstrate how a Quad bike can roll laterally over a rider without causing any injury. The rider stood up and walked away from the incident.

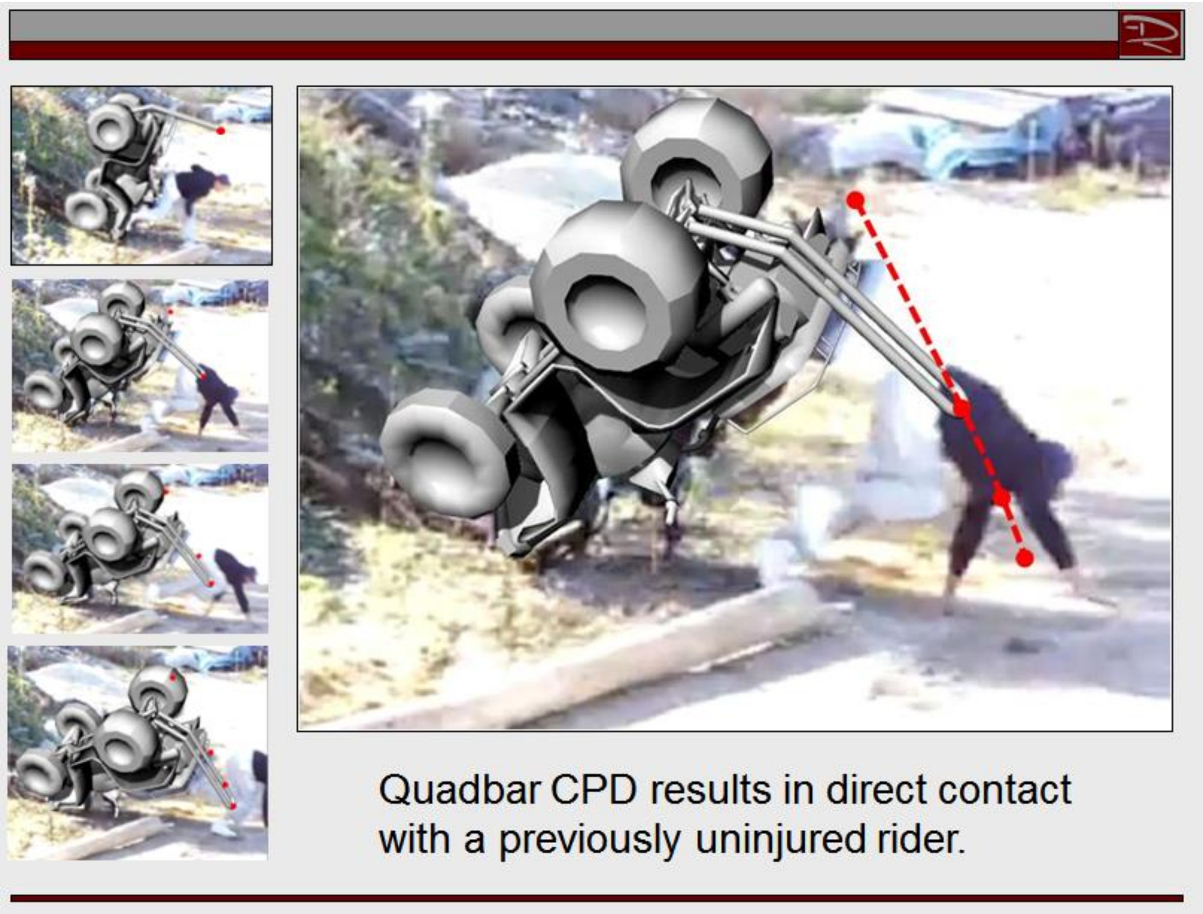

Figure 4: Van Ee et al. (2012) graphically present the hypothesis that a vehicle pitching forward over a rider could firstly obstruct the rider from potentially running out from under the Quad bike (left frame sequence) and secondly could potentially stab a person in the head, neck or back.

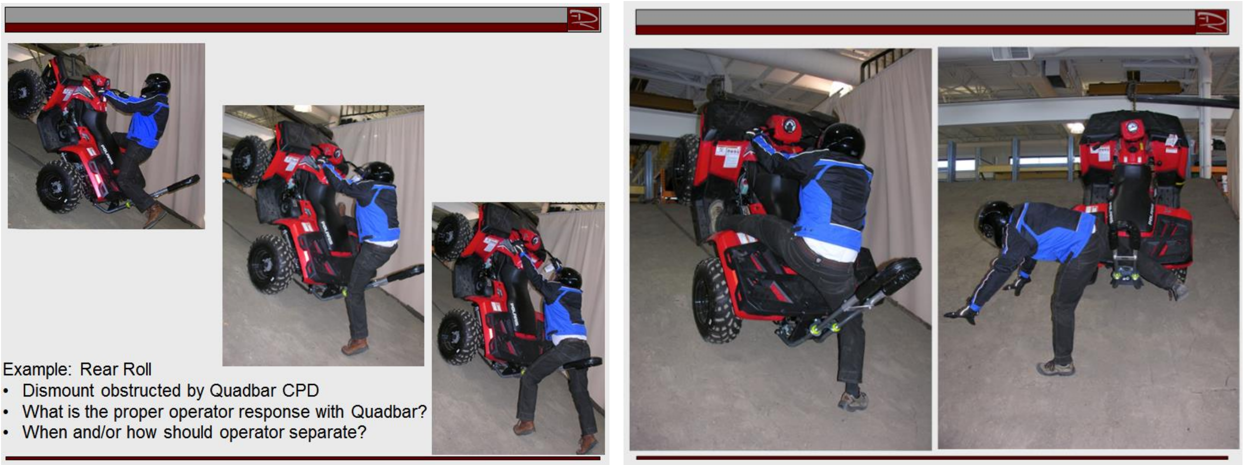

Figure 5: Van Ee et al. (2012) demonstrate how a Quadbar (CPD) can potentially obstruct separation from Quad bike during rearward pitch rollover crash.

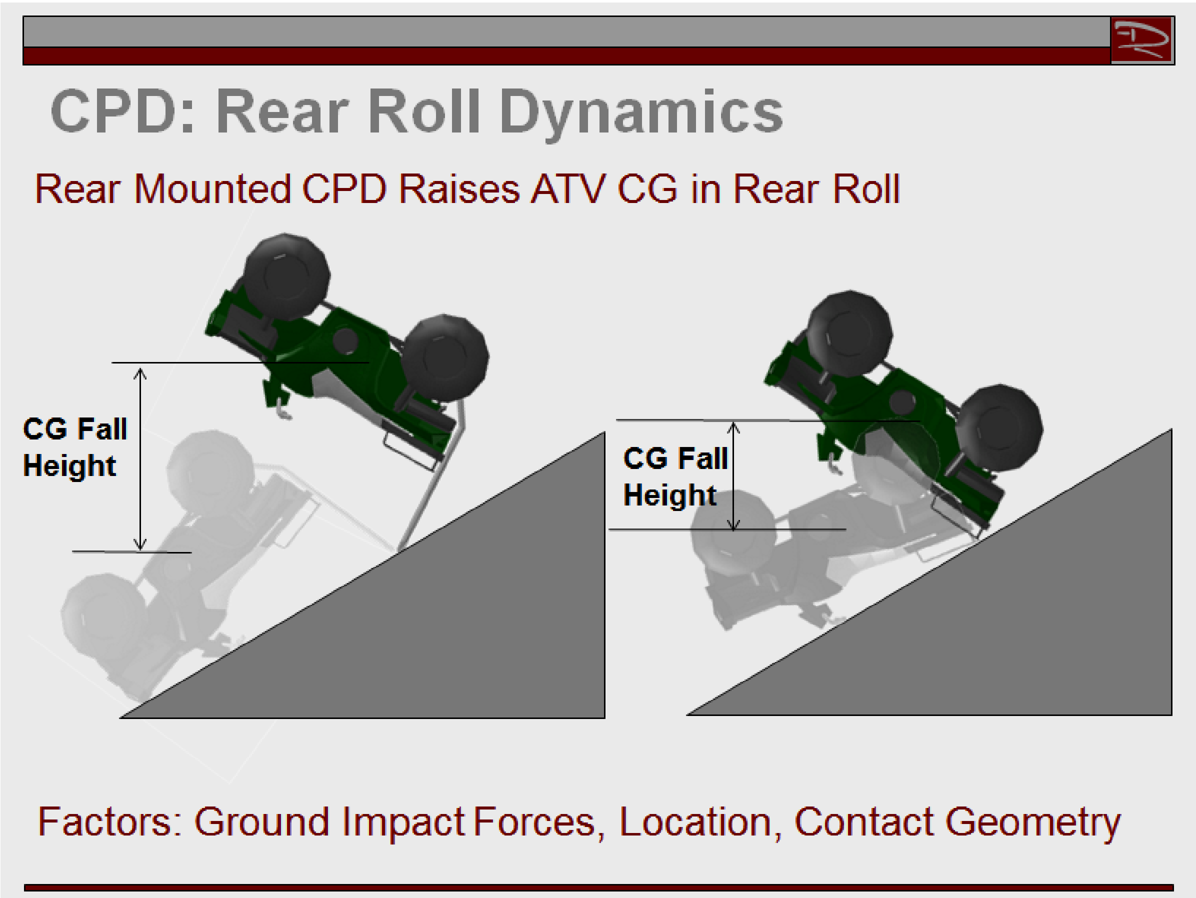

Figure 6: Van Ee et al. (2012) graphically present the hypothesis that a Quadbar (CPD) could potentially raise the vehicle's Centre of Gravity (CG) in a rearward pitch such that impact energy and likely impact forces impart to the rider could potentially be higher.

2.4 OPDs and Principles of rollover crashworthiness

The best way to protect a person being transported by a four wheel vehicle (in contrast to a two wheel vehicle such as a motorcycle) that is subjected to a rollover crash, is to place them inside a vehicle that has a protective structure and appropriately restrain the occupant during the crash event (assuming that the vehicle is large enough for the person to be placed "inside", i.e., that it is large enough to have an "inside", which motorcycles and Quad bikes in their current configurations are not). Over the past several decades, beginning around the late 1930's, the major advances in understanding how human injury occurs in crashes and how to mitigate them was in large the result of Hugh De Haven's research efforts at Cornell University (Young et al., 2006). Over time this understanding was used to start to design vehicles to protect automobile occupants in vehicle crashes, and included the work of Colonel John Stapp, a colleague of Hugh De Haven.

While the origins and growth of this vehicle safety movement was due to the input and experience of many such people, Hugh De Haven (1952) is often attributed with being the "Father of Crashworthiness principles and Research" and the person who created the original theories of crashworthy design. He adapted simple "packaging principles" to show its relevance to protecting occupants during crashes. These principles are still valid today and yet often ignored in the design of mobile structures, which includes the human body (e.g. helmets) when considering occupant protection. Indeed, there is a long history (some involving the first two Authors) of established evidence of how to protect an occupant seated in a vehicle that is subjected to a rollover crash. Crush protection and containment using an appropriate restraint system is at the heart of a good crashworthy design (Rechnitzer and Lane, 1994; Digges and Malliaris; 1998, Young et al., 2006; Grzebieta et al., 2007).

Considering the above context, the Authors also unequivocally subscribe to the view that if first principles of crashworthiness design are ignored or violated, then it is no surprise, indeed it is axiomatic, that severe injuries will be an outcome of vehicle crashes.

What is an OPD? From a risk management perspective an OPD is intended as an engineering control akin to machine guarding which limits contact and/or entanglement with the hazard; the hazard being the kinetic energy and mass of the Quad bike. Through this function, the OPD limits the dynamic and static forces applied to the Quad bike operator. An OPD may perform those functions by limiting the number of ¼ rolls of the quad bike – which facilitates separation of the operator from the vehicle - and/or by increasing clearance (survival space) under the quad bike as it rolls so that the operator can crawl out from under the Quad bike. Current commercially available OPD's in Australia are the Quadbar and the Lifeguard. While this may be the intention there are however, a number of limitations with OPDs such that an increase in injury may occur in certain situations.

Retrofitting an OPD has been encouraged by a number of Quad bike safety stakeholders and is currently being considered by regulators. On the other hand, sections of industry actively warn against this recommendation for the above reasons (Figures 3 to 6) and on the basis of computer analyses carried out by Munoz, et al. (2007) where they stated "*for the population of overturns, the Quadbar would cause approximately as many injuries and fatalities as it would prevent*", i.e. industry claims OPDs are likely to do as much harm as good thus simply substituting one injury mechanism for another.

For Quad bikes, the Authors concur with the Industry perspective to the extent that OPDs do not comprehensively satisfy the 'ideal' fundamental crashworthiness criteria for rollover, i.e. containment and crush protection. Nevertheless, the Authors are at the same time of the opinion that OPDs can improve rollover crash survivability for some vehicles as has been demonstrated in the successful two post ROPS program (see Day & Rechnitzer, 1999) in the case of tractors, and as was demonstrated subjectively by the rollover crash tests presented in this report. This is further discussed in the rating and conclusions sections of this report.

ROPS systems

A well designed SSV with a ROPS and appropriate seatbelt restraint (3 point or harness) can provide good protection in rollover crashes that typify farm rollover incidents as identified in Coronial data. For this reason the vehicle type (SSV or Quad bike) was not distinguished as such when assessing rollover crashworthiness protection (similar to assessing the vehicles for static stability and the dynamic handling). The focus of the rating system is to identify for the workplace/farming consumer which vehicle offers the best protection in a rollover crash regardless of vehicle type protection system (ROPS with Seat belts or only an OPD), except that some systems offer more protection than others, with points rated accordingly.

Critical to occupant protection with a ROPS is the wearing of the restraint to prevent and restrict full and partial ejection during the crash. Hence, emphasis is placed in the rating process by means of awarding points to vehicles that had as a minimum (a) a 3 point or harness (4 point or 5 point) seat belt and (b) the rider is audibly warned or the vehicle increases the likelihood that drivers/riders/occupants wear a seat belt via a seat belt interlock system.

To date there have not been any reports that the Authors are aware of a Quadbar or a Lifeguard having caused an injury, whereas there have been anecdotal reports claiming the OPD likely saved a rider from injury. However, it is important to note that Australia does not have in place a detailed accident data collection protocol for Quad bikes or SSVs, wherein prevalence of OPD or ROPS related injury events is collected. Moreover, currently what is not known is the extent to which roll events that would not be injurious or fatal would have become injurious if an OPD was fitted.

The Authors have reviewed the 53 farming death Coronial cases and identified that fitment of an OPD could have potentially assisted in reducing the rider's injuries or being asphyxiated in around half of these incidents. There were a number of rollover crashes where the OPD would not have assisted the rider. There was one report of a fatality in the 109 cases investigated where a Quadbar was fitted to the Quad bike. However, the Quadbar did not influence the manner in which the operator was killed, i.e. the operator was ejected and died of a brain injury as a result of an impact. There was another event where an SSV with ROPS rollover and the unrestrained occupants were ejected and killed.

2.5 The rollover crashworthiness tests undertaken

At the start of this project, the project team considered that it would be possible - though challenging - to conduct testing which would discriminate between the rollover crashworthiness of different Quad bike models and SSVs in order to derive a discrete rating score for each vehicle within the same test and rating system.

Consideration was given in the initial proposed crashworthiness rating system to a score that separated vehicles with and without a ROPS structure. In that proposal a Quad bike could potentially score up to 'two stars' depending on its performance in rollover crash tests either using an Anthropomorphic Test Device (ATD), also known as a crash test dummy, or instrumented floor. A vehicle with a ROPS could score a minimum of 'three stars', if it demonstrated compliance with a relevant ROPS standard. The ability to achieve four or five stars was based on performance in dynamic rollover tests that measured the responses of an ATD against impact responses and ejection. After consideration of the initial proposal, various changes were made that led to the simplified final adopted test and rating protocol presented later in this report.

Through the exploratory rollover crashworthiness tests using the Motorcycle ATD (MATD) as the rider/driver, that were undertaken for this purpose, it became apparent that it was unrealistic currently to be able to discriminate the rollover crashworthiness between different Quad bike models, based on such rollover testing – however discrimination between vehicle types – Quad bikes and SSVs - was realistic.[5]

Further, it was also evident from such testing, that due to the stochastic ('hit and miss') nature of severe injury risk to a rider and the large range of possible relevant rollover test permutations, it was unrealistic to continue with such tests for ratings of Quad bikes.

Indeed it was deemed by the Authors that the term "Crashworthy Quad bike" was essentially a contradiction in terms. For this reason for the Quad bike type, all were assumed to be rated equally for rollover crashworthiness, and all were assigned the same arbitrarily low 5 point minimum level rating when assessing rollover crashworthiness

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[5] Ideally if the resources and time were available a hundreds of similar rollover tests could be conducted both for Quad bikes and SSVs and the injury results recorded and compared. This would provide a robust assessment of risk of injury and rating for both types of vehicles. However, this is a totally unrealistic expectation and therefore pragmatic approach is taken based on the best available scientific engineering information has been applied by the Authors.

protection.[6] Fundamentally Quad bikes do not and cannot satisfy fully the well-known principles of occupant protection in rollover crashes even with an OPD attached, i.e. good containment and crush prevention.

Nor was it possible to discriminate Quad bike crashworthiness performance based on current real world crash information (in contrast to passenger vehicles). This is due to the absence of make/model/year (MMY) crash involvement injury data and exposure data. This fundamental deficiency with data collection for Quad bikes (and SSVs) is still an impediment to advancing Quad bike safety. Differences between the geometry of the Quad bikes and the potential clearance between the models and a ground plane with regards to survival space requirements suggested that rating on this parameter would not discriminate between Quad bike models. For Quad bikes, this leaves rollover crash prevention as the primary control mechanism to prevent injury in rollover (together with personal protective equipment - appropriate helmets, etc.), with the fitment of OPDs as a secondary measure that could reduce injury risk in some circumstances (but may increase it in other circumstances though no real world injury examples have been presented to date).

In contrast to Quad bikes, the SSVs do adhere in general to rollover crashworthiness principles, in that they are typically fitted with ROPS, seatbelts and various degrees of containment measures which combine to keep the occupants within a protected space. As the effectiveness of such designs in terms of severe injury prevention can vary widely, it is possible to discriminate and rate SSVs, as a first step.

The real proof of the validity of such ratings and the design improvements explicit to the rating, will then depend on proper, systematic collection of real world crash data involving Quad bikes and SSVs.

Considering the above context, it was decided that the rollover crashworthiness test program should consist of 65 tests, carried out in four different test series (see Section 2 Crashlab Rollover Crashworthiness Report – Attachment 1) in the order presented, namely:

1. Measurements of static ground contact force for the Honda TRX500 with and without an Operator Protection Device (OPD) on its left and right side and when inverted. The mass difference between different model Quad bikes was not sufficient to provide significant discrimination in terms of asphyxia potential, as in most cases the 50 kg asphyxia load criterion (McIntosh and Patton, 2014b) would be exceeded.
2. Inspection and measurements of Side by Side Vehicle (SSV) occupant retention in accordance with the United States (US) American National Standard for Recreational Off-Highway Vehicles ANSI/ROHVA 1-2011 with additional requirements applied, as discussed in Section 2.5.2;

[6] There is currently no exposure data available that enables an independent rollover injury risk probability to be determined for Quads and SSVs and thus in the absence of such data the Authors have made the above noted assessment.

3. Vehicle and rider/driver dynamic rollover tests consisting of positioning a MATD in the operator's position of a Quad bike or Side by Side Vehicle, tilting the vehicle to an angle at which rollover would occur, and releasing the vehicle from an initial static position to rollover to observe 'survival space'[7] and functionality of the OPD, and in the case of the two SSVs the ROPS and restraints.

4. Side by Side Vehicle (SSV) ROPS structure load tests consisting of applying a lateral load followed by a vertical load then a longitudinal load to the vehicle ROPS whilst recording the deflection and noting the structural integrity, in accordance with the ISO (2008) test option for the US ANSI/ROHVA 1-2011 requirements. (Note that there are two test methods for compliance: the ISO 3471:2008(E) (ISO, 2008) method and the OSHA method (Code of Federal Regulations). In this study, the ISO 3471:2008(E) test method was used).

All these tests were carried out at the Roads and Maritime Services Crashlab laboratory facility in Huntingwood (an outer suburb of Sydney), NSW, Australia by Test Engineer Mr. Drew Sherry together with other Crashlab staff and assistance from Mr. David Hicks from TARS. This was done under the supervision of the Crashlab Manager Mr. Ross Dal Nevo and under the guidance of Team Leader Prof. Raphael Grzebieta and Adjunct A/Prof. George Rechnitzer from TARS, with advice from Dr. Andrew McIntosh and also Mr. Keith Simmons.

Prior to carrying out the vehicle and rider/driver rollover tests a series of 12 development and research tests were also carried out at Crashlab by their staff together with TARS researchers and researchers from DRI and representatives from the Federal Chamber of Automotive Industries (FCAI). These tests consisted of 5 vehicle and occupant rollover tests using the Honda TRX500 and MATD, and 7 chest loading tests conducted with the MATD.

2.5.1 The Quad bike ground contact load tests

Measurement of resting ground contact forces was carried out to determine the load distribution for a typical work farm Quad bike, in this instance the Honda TRX500, and what potential load could be expected to transfer to the rider when the vehicle rolled over, onto its side and when inverted. McIntosh and Patton (2014b) identified from scientific literature that a load of around 50 kg applied for 10 minutes to the chest to be an applicable test criterion for mechanical asphyxia of a person in the context of a Quad bike rollover.

It was identified from the 37 pinned fatality cases analysed (out of 54 workplace fatalities - 53 farm place and 1 forestry) that riders were predominantly pinned on the left (13) or right (7) side, i.e. a total of 20 cases or around 37% (≈1/3). Ten (10) were pinned with the vehicle upside down and 2 with the vehicle upright. The contact load tests were carried out to assess if any of the OPDs could have assisted with reducing the contact loads in such circumstances, and hence the risk of crush or asphyxia.

[7] 'Survival space' is intended to mean here the space left between the upturned Quad bike and the ground from which a rider can crawl

The test method used to measure the contact loads, is summarised in Table 1 below. The test method not only included measuring the weight at contact points when the vehicle was rolled onto its side and when inverted, it also included contact load measurements when the vehicle was rolled partially to the left side (rolled between 100° and 170°) and only measured if the vehicle would stabilise in this position without external support.

When rolled 90° the Quad bike rested on the same four contact points irrespective of whether an OPD was fitted or not. The ground contact points were the left front wheel, left rear wheel, left front plastic wheel guard, left rear plastic wheel guard. The front left wheel applied the greatest load, typically accounting for one third of the vehicle mass of 293kg. The load split front to rear however was almost equal. Only in one of the four contact points (left front plastic wheel guard) was the load less than 50 kg. The contact loads ranged from 42kg to 114kg.

	Ground Contact load range (kg)		
Orientation of the Honda TRX500 Quad	Quad only	With Quadbar OPD.	With LifeGuard OPD.
Total Load	293	303	309
On wheels	68 to 77	71 to 77	71 to 84
On side	42 to 114	31 to 118	36 to 113
Inverted	74 to 131	27 to 274	31 to 133
Inverted and partially rolled on side	66 to 146	66 to 146	54 to 140

Table 1: Ground contact Loads for the Honda TRX500 test Quad with and without OPDs (from Table 2, CrashLab Crashworthiness Test report)

When inverted the vehicle had ground contact points at the front of the vehicle, typically the handlebars or headlight shroud, and a single point at the rear of the vehicle, either the OPD if fitted or the rear load rack when the OPD was not fitted. Typically a large portion of the vehicle mass was applied through the ground contact points at the front of the vehicle. Without an OPD fitted 75% of the vehicle mass was applied to the ground through the two handlebars with only 25% applied through the rear load rack. However none of the loads were less than 50 kg, and ranged from 74kg to 131kg.

With an OPD fitted and the vehicle inverted, the proportion of load applied through the rear vehicle contact point reduced further. The Lifeguard applied 16% of the load (48 kg) with the handlebars and front load rack applying the remaining load with a range of 31kg to 133kg.

The Quadbar applied less than 10% of the load (27 kg) with the headlight shroud at the front of the quad bike applying more than 90% of the load at a single contact point (i.e. 274kg).

However, when the vehicle (with an OPD fitted) was tilted to one side and it settled in a stable position, the load applied by the OPD contact point at the rear of the vehicle accounted for approximately one third of the vehicle's total mass for both OPDs (i.e., 114kg for the Lifeguard and 90kg for the Quadbar). In this configuration all of the contact loads were over the 50 kg limit criterion for mechanical asphyxia if the McIntosh and Patton (2014b) criterion is used.

2.5.2 Side by Side Vehicle (SSV) occupant retention systems test results

The Side by Side Vehicle (SSV) occupant retention device and manufacturer's safety/warning label inspections and retention tilt tests are based on those specified in the *American National Standard for Recreational Off-Highway Vehicles ANSI/ROHVA*[8] *1-2011*, Section 11 *Occupant Retention Systems*. Two inter-related characteristics were assessed.

Occupant Retention Systems Zone Restriction.

This is a largely inspection based evaluation of the SSVs. The SSV is divided into four retention zones (see Figure 7):

- **Zone 1- Leg /Foot** (requires a raised entry way or barrier to prevent foot/ leg ejection with a minimum force resistance requirement).
- **Zone 2** – Shoulder/Hip. Requires a lateral retention barrier or restraint for the torso.
- **Zone 3** – Arm/Hand. This can be met by permanent barrier(s) – doors, nets, or other suitable devices.
- **Zone 4** – Head/Neck Restraint to prevent lateral head excursion outside the vehicle width. Note that such "prevention" of lateral head excursion is beyond what is required in the US ANSI ROHVA 1-2011 Standard.

The results of the retention devices inspection are provided in Appendix 1.

The retention devices, including operator warning labels, were inspected and components tested where required (e.g. Zone 1 Leg/Foot barrier) to assess whether the SSV complied with ANSI/ROHVA 1-2011 as shown in Table 2.

Occupant Retention Systems Performance.

The Occupant Retention System performance tests consisted of placing the MATD in the front outboard seating position of an SSV and restraining the MATD by fastening the vehicle's seatbelts. The standard also permits the MATD's gripping hands to be adjusted to either grip the steering wheel when in the driver's seat or any hand outboard grips provided when in the passenger seat. The vehicle was placed on the single axis tilt table and tilted about its longitudinal axis to an angle of 45°. A number of vehicles were also tested with the

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[8] It is noted that the ANSI-ROHV standard came into force for SSV vehicles on the market in 2014. The SSV vehicles purchased for the project in late 2012, would not necessarily have had to be compliant with this.

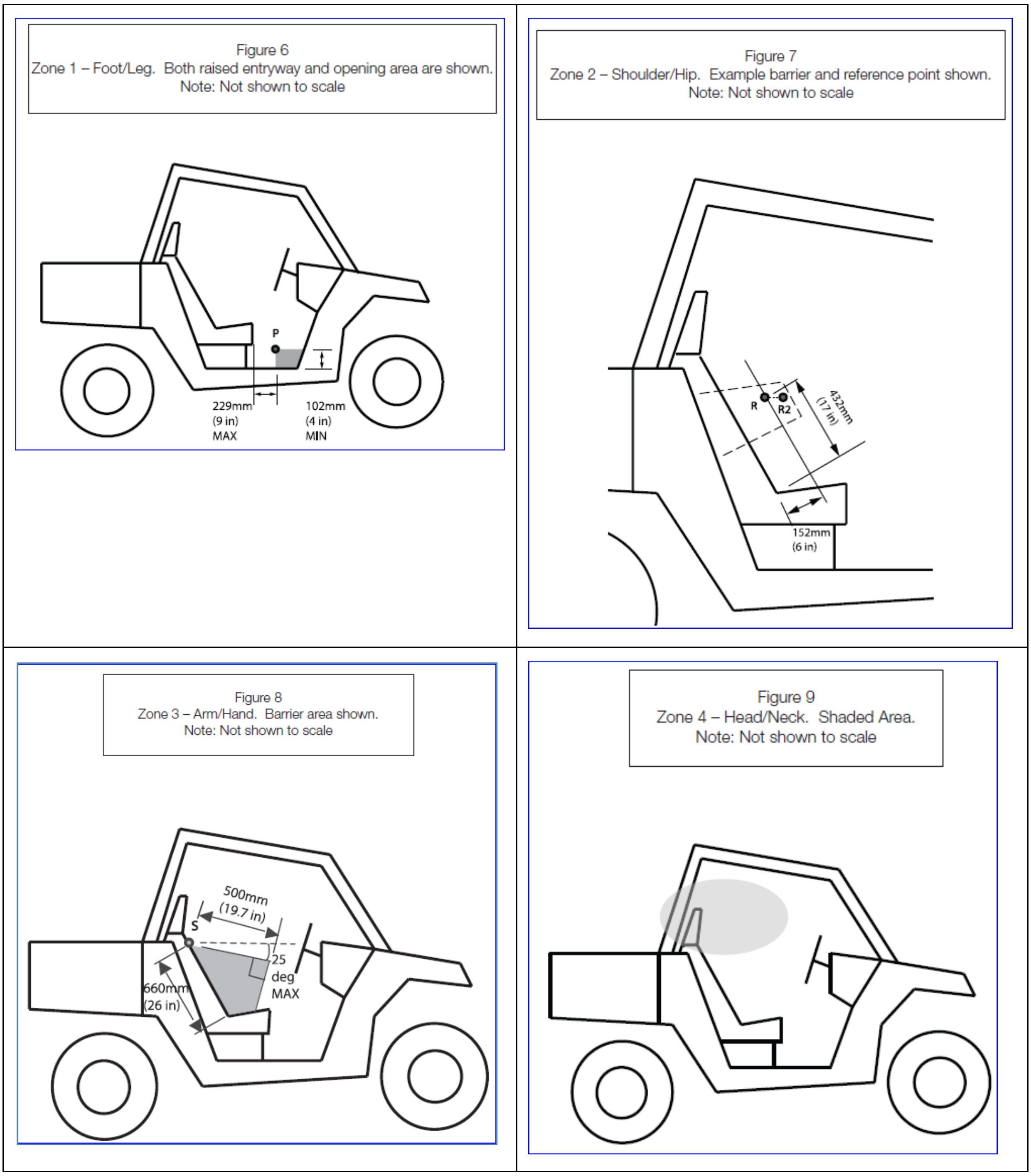


Figure 7: Occupant Retention System Zone Restriction for Zones 1, 2, 3 and 4. Figure numbers in frames are from ANSI/ROHVA 1-2011 standard.

MATD positioned in the passenger seat with both hands resting on the MATD's thighs without gripping any part of the vehicle.

The performance requirements of ANSI/ROHVA 1-2011 state that the torso of the ATD must not extend beyond the plane 127mm outside the vehicle width and that the hands and arm of the ATD must not extend beyond the plane 178mm outside the vehicle width. However, the requirement of the Australian Terrain Vehicle Assessment Program (ATVAP) developed by the Authors deducts points for any extension outside the plane of the vehicle width.

Points are also deducted if the vehicle does not have a seat belt or the seat belt is not either a 3 point seat belt or harness (4 or 5 point). All the SSVs met the *Occupant Retention System* tilt table test performance requirements of ANSI/ROHVA 1–2011, but not all met the ATVAP Zone Restriction Tests. Points were not awarded if any part of the ATD extended outside the vehicle width[9].

The SSV *Occupant Retention System* test results are presented in Table 3 of the Crashlab report (Attachment 1) and also attached in Appendix 1 of this report.

	Activity
Seat Belt	
1	Each Seating Position has a minimum Type 2 (3-Point) Occupant Restraint (ANSI/ROVA 1:11.1)
2	If Yes, does the Occupant Restraint meet or exceed SAE J2292 (i.e. warning label displayed)
Seat Belt Reminder	
3	Is a lighted seat belt reminder fitted
4	Does the reminder remain active for at least 8 seconds after the ignition switch is turned on
5	Is the light visible to the seated operator
Zone 1	
6	Is a Leg/Foot barrier fitted
7	Type of barrier (Doors, Raised Entry or other Suitable Devices)
8	Does the barrier encompass the area defined in Figure 1
9	Does the barrier interfere with vehicle operation or affect visibility
10	Can barrier withstand a horizontal side force of 222N at the centroid of area defined by Point P
Zone 2	
11	Is a Shoulder/Hip barrier fitted
12	Type of barrier (Doors, Nets or other Suitable Devices)
13	Does the barrier encompass the area defined in Figure 2
14	Does the barrier interfere with vehicle operation or affect visibility
Zone 3	
15	Is a Arm/Hand barrier fitted
16	Type of barrier (Doors, Nets or other Suitable Devices)
17	Does the barrier encompass the area defined in Figure 3
18	Does the barrier interfere with vehicle operation or affect visibility
Zone 4	
19	Is a Head/Neck barrier fitted
20	Type of barrier (Head Rest, Nets or other Suitable Devices)
21	Do these devices compromise the visibility and mobility a seatbelted, helmet wearing rider
Operator Warnings Labels	
22	Use of Seat Belts recommended
23	Use of Helmets recommended
24	Occupant being in the seated position recommended
Other/Comments	
	Seat Belt conformance not labelled
	Passenger Hand Hold

Table 2: Inspection of SSV seatbelt and occupant retention features to the ANSI/ROHVA 1-2011 and for the ATVAP rating process.

[9] These Tests are effectively 'static', and thus additional excursion may occur if a dynamic rollover test was conducted. Partial ejection can lead to serious injury in a rollover. An effective containment system, apart from 3 or 4 point seat belts, would include side doors or side seat bolsters, and possibly a side mesh to reduce/ help prevent head, torso and arm excursions during a rollover crash.

2.5.3 Quad bike and SSV rollover tests

The Honda TRX500 Quad bike with a MATD rider was subjected to rollover tests in nine (3 x 3 matrix) configurations, i.e. roll direction (lateral roll, rearward pitch and forward pitch) and OPD (none, Lifeguard OPD and Quadbar OPD). Two SSVs were also tested for comparative purposes, i.e. the Tomcar and the Yamaha Rhino.

Each vehicle was positioned on a single axis tilt table with the tyres located 1,000mm from the 'lowered' edge of the tilt table. The vehicle brakes were applied and the tyres located on expanded mesh anti-slip plates so the vehicle would tip over rather than slide down the tilt table surface (See Figure 8 to Figure 12 and Crashlab report Appendix D in Attachment 1). The Quad bike and ATD were tethered to the table to prevent premature vehicle tip over. The tilt table was slowly raised from horizontal to the angle at which the vehicle alone would rollover, plus 5 degrees (to ensure vehicle overturn). When the desired angle was reached, the tethers securing the vehicle and ATD were simultaneously released, allowing the vehicle to rollover under the force of gravity and impact with the ground plane which was horizontal (i.e. at an angle of approximately 130 to 150 degrees to the tilt table).

Prior to carrying out the above rollover tests, a series of exploratory tests were carried out where the TRX500 was raised to 1,500 mm from the 'lowered' edge of the tilt table. These tests were also documented and results are presented in the Crashlab report in Attachment 1.

In all three lateral roll Honda TRX500 Quad bike tests the first point of contact with the ground was the MATD head. The worst case in terms of injury is the forward pitch test as is clearly evident in Figure 11b. In this case the MATD neck was broken in "half". The MATD neck also fractured in the exploratory tests albeit in the first side rollover test.

In all tests the MATD was instrumented. The MATD was supplied and calibrated prior to testing by Dynamic Research, Inc. (DRI). The recorded MATD instrument data from each test were processed in accordance with ISO 13232 using software provide by DRI. Whilst the MATD instrument data were collected and analysed, it was decided not to use the output from this process for the rating system. This is discussed further below.

The results of all the rollover tests with the Honda TRX500 and the two SSVs are presented in Table 5 in the Crashlab Report in Attachment 1.

Performance of the Quadbar and the Lifeguard OPDs

No OPD - Without an OPD fitted the Quad bike rolled onto the MATD and came to rest on the MATD with the MATD located between the Quad bike and the ground (2nd row frames in Figure 8 to Figure 10). When reviewing the videos it appeared that a large portion of the vehicle's weight is being transferred to the MATD. The vehicle came to rest on top of the MATD in the lateral roll and forward pitch scenarios and rolled off in the rearward pitch scenario.

The Lifeguard - With a **Lifeguard OPD** fitted the Quad bike rolled over and on top of the MATD such that the rear of the Quad bike was being supported by the Lifeguard during this rollover/pitch process. The Quad bike did not load the MATD as can be ascertained in the 3rd row frames in Figure 8 to Figure 10. The Quad bike came to rest over the MATD in the lateral roll and forward pitch scenarios. In the rearward pitch scenario, the vehicle rolled off to one side after having been over the MATD. The Lifeguard OPD increased the clearance (survival space) under the Quad bike relative to no OPD.

However, with the Lifeguard, a concern regarding the rearward pitch test was noted. The MATD was found to fall into the hollow part of the Lifeguard as shown in Figure 11a. The belted flexible part of the device distorted such that the MATD's lumbar spine contacted the upper edge of the distorted belt portion of the device. The belt then straightened out to the position shown in Figure 10 (frames in 3rd row) and the Quad bike subsequently rolled away off the MATD.

The Authors are concerned that this distortion in rearward pitch would present a serious hazard to a rider involved in such an incident particularly if the belt impinged on the rider's spine (as it did in this test) and if the Quad bike fell from a higher initial height as in the exploratory tests, i.e. 1,500 mm from the 'lowered' edge of the tilt table. The device would need to be redesigned to ensure this would not occur. Moreover, if for example netting were used to prevent such rearward ingress of the rider, the rider's head would be further forward as is evident in Figure 11a). This in turn would position the rider's head such that it would be directly under the front handle bars of the vehicle as it rotates downward towards the rider. This again would present a potential hazard.

Quadbar - With a **Quadbar OPD** fitted the Quad bike did not fully roll onto the MATD (4th row of frames in Figure 8 to Figure 10). In the rearward pitch the vehicle remained vertical as shown in the 4th row of frames in Figure 10. However, it was observed that when the fall height was larger, as in the case of the exploratory tests where the vehicle was placed 1,500 mm from the 'lowered' edge of the tilt table, the Quadbar deforms as a result of the impact force but still maintains the rear of the vehicle above the MATD as shown in Figure 12. In regards to lateral roll and forward pitch the Quadbar kept the rear of the vehicle above the MATD without allowing the Quad bike to apply load to the MATD. The Quadbar OPD increased the clearance (survival space) under the Quad bike relative to no OPD in the inverted position.

In the context of the crashworthiness scoring, the performance of the OPDs with the Honda TRX500 was considered to represent the performance of the OPDs with all Quad bikes in the sample. Therefore, these tests were not reproduced for each vehicle and OPD combination.

Lateral Rollover tests of SSVs

Two SSVs were also tested in lateral roll (Figure 13) with the MATD located in the driver seat on the 'low-side' of the tilt table. Each vehicle had previously been subjected to Roll-Over

Figure 8: Quad Tests: Lateral rollover: Top – setup; 2nd row – baseline; 3rd row – Lifeguard OPDS; 4th row – Quadbar OPD.

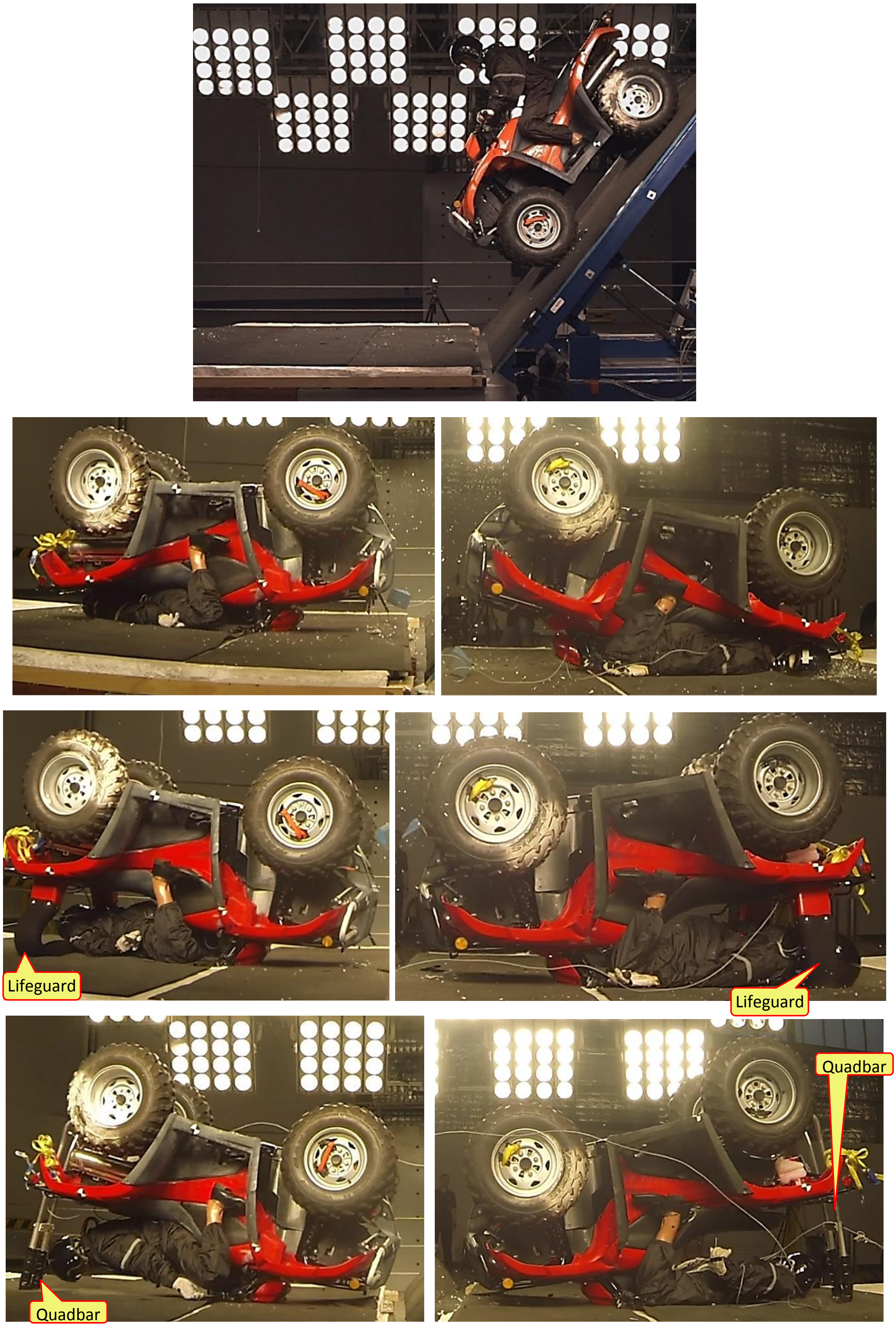
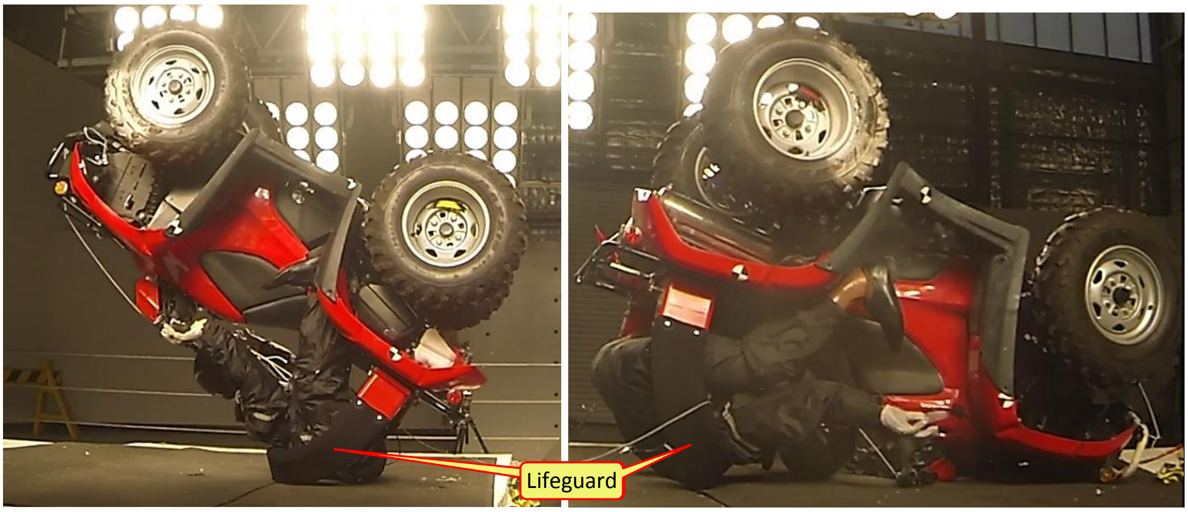


Figure 9: Quad: Forward pitch: Top – setup; 2nd row – baseline; 3rd row – Lifeguard; 4th row – Quadbar.

Figure 10: Quad Tests: Rearward pitch: Top – setup; 2nd row – baseline; 3rd row – Lifeguard; 4th row – Quadbar.



a) Rearward pitch with Lifeguard showing how ATD is not restrained from falling into gap.

b) Forward pitch demonstrating how rider can receive serious cervical spine injury. MATD neck was fractured twice during testing.

Figure 11: Quad Tests – Rearward and Forward Pitch, including with Lifeguard OPD.

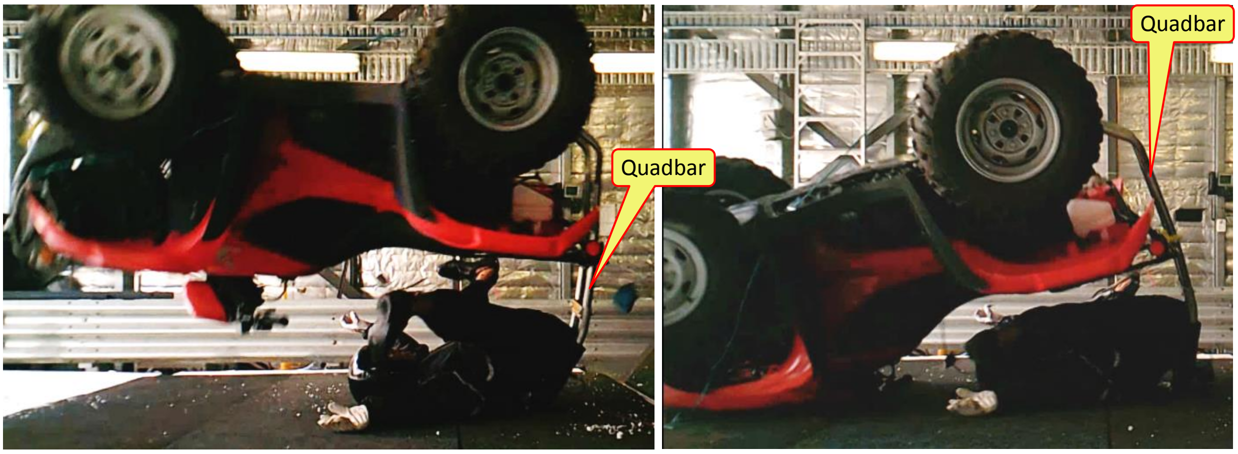


Figure 12: Rearward pitch from top of tilt table demonstrating how Quadbar has bent during impact but still maintains survival and hence crawl out space for rider.

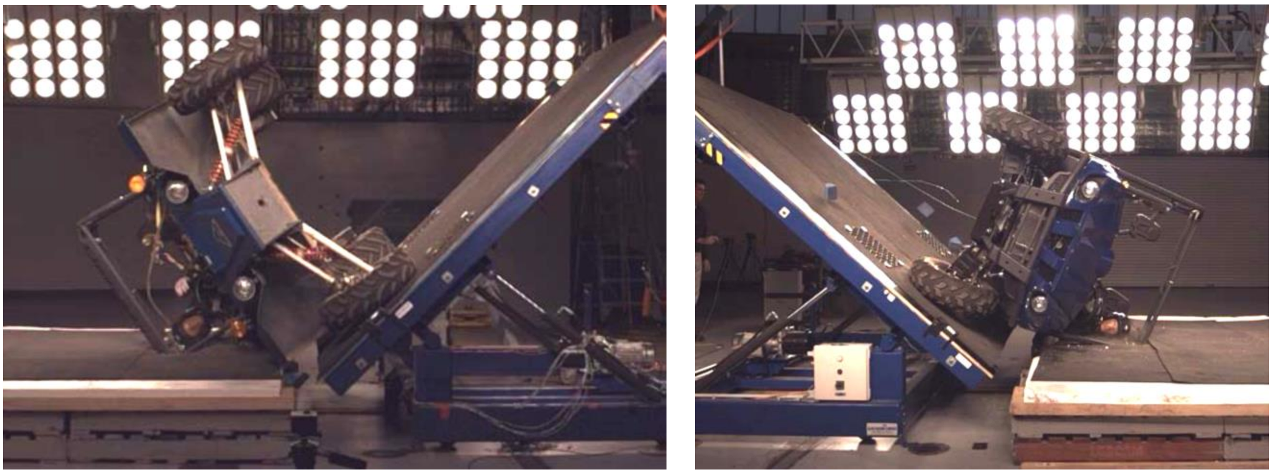


Figure 13: Rollover testing of Tomcar (left) and Yamaha Rhino (right) SSVs.

Protective Structure loading, and as such each vehicle ROPS had minor deformation prior to rollover testing.

When tested in roll the Tomcar TM2 ROPS made initial contact with the ground and resisted the vehicle from rolling over. The ROPS did not fail or collapse and exhibited approximately 35mm of permanent lateral deformation after the test. The MATD torso was well contained, however the head impacted the ground surface after the ROPS made contact and arrested the vehicle roll.

When roll tested, the Yamaha Rhino vehicle ROPS made initial contact with the ground and resisted the vehicle from rolling over. The ROPS did not fail or collapse and showed minimal deformation after the test. The MATD head and shoulder contacted the ground surface. These two lateral rollover tests support the need for SSV operators to wear a helmet.

Impact Response Data of the MATD

In regards to the impact response data[10] from the MATD, in 9 out of 10 of the Quad bike evaluation tests and in 5 out 5 of the Quad bike exploratory tests the measured results indicated no risk of serious injury (i.e., AIS greater than or equal to 3), as listed in Table 5 of the Crashlab Report in Attachment 2, when processed in accordance with ISO 13232 using software provided by DRI. In two of the exploratory tests a knee “varus vulgus” (lateral bending) injury-indicating shear pin fractured, indicating a probable knee dislocation injury (AIS 2 (moderate severity)) in these two tests. The first of these “two injurious” exploratory tests, in which there was also an AIS 2 head (concussive) injury recorded, was with the baseline TRX500 onto a relatively rigid plyboard surface (covered with a rubber mat) atop three timber pallets. The second of these exploratory tests was with the ballasted spray tank

[10] Anthropomorphic Test Devices (ATDs or crash test dummies) are mechanical systems which measure accelerations, forces and displacement providing impact response data. These mechanical measurements have been calibrated against ‘injury assessment reference values” derived from real world crash data, and cadaveric, animal and human volunteer test data, to determine the risk of different types of injury.

fitted to the TRX500, onto the rubber mat-covered 100 mm thick polystyrene foam plus two timber pallets. This simulated ground surface was considered more representative and which became the standard ground surface for the 10 Quad bike tests from 1,000 mm initial Quad bike height.

It should be noted that on the first forward pitch test in the nine configuration test series, and in the first lateral rollover test in the exploratory test series, the MATD neck was mechanically fractured without a corresponding injury recorded. This mechanical fracture can occur because the MATD does not have a lateral shoulder stop for the neck[11].

This component was replaced in both cases with a standard Hybrid III 50th percentile male ATD neck to conduct the remaining tests. In the development test series the MATD exhibited some physical damage (broken right shoulder clavicle, broken knee pins, broken fingers and thumb) during the tests (see Attachment 1, Table 5 in the Crashlab Report: Quad bike performance project, Crashworthiness testing, Special Report SR2014/003).

Table 5 of the Crashlab Report (Attachment 1) also indicates the head injury criterion (HIC) in the exploratory tests Latroll_01 (onto the rubber mat-covered plyboard surface) was 622, a value just below the recommended criteria limit of 700 commonly adopted in vehicle crashworthiness studies (Eppinger et al., 2000) and as noted above corresponding to a predicted AIS 2 (concussive) injury.

Table 5 of the Crashlab Report (Attachment 1) indicates that in the last of the 10 tests (Test G140088), the forward pitchover with the baseline TRX500, there was a fatal injury recorded. The maximum AIS was 6 and the probability of fatality was 1.0. This was due to an extended chest loading exceeding 551 N. This exceeds the asphyxiation criterion proposed by McIntosh and Patton (2014b).[12]

Table 6 in the Crashlab Report (Attachment 1) shows the results of a series of tests carried out to assess the chest compression of the MATD and to determine how results compare to current injury criteria recommended by the US National Highway and Transport Safety Administration (NHTSA). The MATD thorax's upper x (anterior-posterior) displacement exhibited a relatively linear response within the range of drop tests. Even with the MATD lying on its back, with the rear rack of an inverted Quad bike dropped from a height of 0.5 metres onto the chest mid sternum, using a timber board across the chest to distribute load and handlebars in contact with ground used as a pivot point, the chest compression was much less than the NHTSA limit of 63mm.

[11] The standards committee responsible for the MATD, ISO/TC22/SC22/WG22, is investigating a prototype shoulder that would provide a more human-like stop for the MATD, in order to eliminate extreme lateral flexion and neck fracture that can otherwise occur in specific types of tests.

[12] This analysis was provided by Dr. John Zellner whose company DRI developed the MATD and associated injury measures.

What this indicates is that the majority of the events that typify a Quad bike rollover are at a much lower energy level than what would more commonly occur in a typical road crash. Moreover, crash test dummies such as the MATD, are tuned to provide measures of acceleration and displacement that are associated with serious injuries that commonly occur in road crashes, and injury risk measures determined from laboratory tests with cadavers and other human surrogates and correlated. Measurements on ATDs, such as chest deformation or femur loads, are typically calibrated for specific load patterns and directions, e.g. axial load of the femur and anterior-posterior compression of the thorax. These loads are more predictable in a contained occupant ATD within a vehicle in comparison to an ejected or separating occupant in a Quad bike rollover test. Therefore, it is possible that an ATD, such as the MATD, may not register some loads during tests because of its design and intended purpose.

A large portion of the workplace farm deaths detailed in the Coronial data were the result of the rider being pinned by the vehicle and asphyxiated without any other major injury. This is a similar outcome to the current tests. The 10 Quad bike overturn tests resulted in one case (forward pitchover with the baseline TRX500) in which there was a predicted potential asphyxiation, using the McIntosh and Patton (2014b) criterion and the MATD and software provided by DRI. Nevertheless, in all of the tests the test videos provided visual indication of varying levels (even if non-fatal) of crush and/or asphyxia potential. Hence, the Authors decided to consider instead observational data in rating the performance of the OPDs in its capacity to provide 'survival space' and room for the rider to be able to crawl out from under the Quad bike.

In summary, in these limited (low speed) test series, typically, without an OPD fitted, the vehicle came to rest on the MATD, imparting a load. Typically, with an OPD fitted, the vehicle came to rest separated from the MATD, or supported the mass of the vehicle above the MATD. In one case, contact between the (lifeguard) OPD and the dummy appeared to apply spinal loads, which could have been injurious to a rider. With respect to the SSVs, in both tests the roll-over protective structure stopped the vehicle from experiencing inverted rollover, and supported the partially inverted vehicle above the occupant without structural ROPS failure. For both vehicles, the MATD exhibited some head excursion from the vehicle resulting in ground surface impact, thus highlighting the importance of wearing a helmet.

2.5.4 SSV Roll-Over Protective Structures (ROPS) load (strength) assessment

The Side by Side Vehicle Roll-Over Protective Structure (ROPS) tests were based on those specified in American National Standard for Recreational Off-Highway Vehicles ANSI/ROHVA 1-2011, Section 10, Roll Over Protective Structure (ROPS), ISO 3471:2008(E) Option (ISO, 2008). Each vehicle's ROPS was tested by applying a uni-axial load to the top of the structure sequentially in three different directions. The load directions in order were:

- Lateral (from driver side towards passenger side of vehicle)
- Vertical (from top of vehicle towards bottom)

- Longitudinal (from front of vehicle towards rear)

Details of how the vehicles were loaded and test results are presented in the Crashlab Report in Section 2. All five SSV vehicles with ROPS were tested against the ISO 3471:2008(E) Option of the ANSI/ROHVA requirements[13]. Table 4 from the Crashlab report details the loads and deformation the vehicles and the ROPS were subjected to and sustained.

Only one vehicle did not meet the specification, namely the 2012 Honda Big Red MUV700.[14] The Honda Big red ROPS yielded appreciably when vertically loaded as shown in Figure 14.

The Tomcar TM2 ROPS was the stiffest, whereas the Honda Big Red ROPS offered the least resistance to load. In lateral loading, the Yamaha Rhino and Tomcar TM2 exhibited the least permanent deformation whereas the Honda Big Red and John Deere Gator showed the greatest permanent deformation, but still acceptable.

Although the Honda Big Red ROPS met and exceeded the initial lateral force requirements (by 16%) and energy requirements (by 40%), the maximum ROPS deflection during the lateral pull test was 242mm with a permanent deflection of 117mm. The ROPS also did not meet the vertical load requirement. The applied force reached 88% of the required load at which point the ROPS structure began to yield and deform. Once the structure had begun to yield, the ROPS continued to deform with a reduction in applied force. The test was stopped with substantial permanent deflection and buckling to the ROPS.

It is noted that the ANSI-ROHVA standard came into force for SSV vehicles on the market in 2014. The SSV vehicles were purchased for the project in late 2012, including the Honda Big

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[13] ANSI/ROHVA Standard Clause 4.7 allows for two options for strength tests of the ROPS; the **US 29 CFR 1928.53 (OSHA)** (Code of Federal Regulations) and **ISO 3471:2008(E) (ISO, 2008)**.

[14] FCAI advised the Authors of the following:

> *"Note that the manufacturer of the subject 2012 Honda Big Red MUV700 indicated that it was only certified to the ANSI/OPEI B71.9 (2012) standard for Multi-Purpose Off-Highway Vehicles and was not built or certified to the ANSI/ROHVA 1 (2011) standard, which "becomes effective beginning with 2014 model year vehicles." Therefore the ANSI/ROHVA standard was not applicable to the build year of the 2012 Honda Big Red MUV700.*
> *In addition, the ANSI/ROHVA 1 (2011) Standard has two options for ROPs strength: ISO and OSHA. The QBPP project chose to use the ISO option. The manufacturer of the 2012 Big Red indicates that there is a convergence between the relevant parts of the ANSI/ROHVA ROPs standard and the ANSI/OPEI ROPS standard with regard to using the test set forth at 29 US Code of Federal Regulations Section 1928.53. Specifically, Annex 10 (Rationale) of the ANSI/ROHVA 1 (2011) standard states:*
>
> > "*A10 Rollover Protective Structure (ROPS). As originally published, all ROVs were required to meet the requirements of ISO 3471, Fourth edition, 2008-08-15, for Rollover Protective Structures (ROPS). Some ROVs are used for work applications and thus are subject to the U.S. Department of Labour Occupational Safety and Health Administration (OSHA) ROPS requirements. ISO 3471 is one ROPS standard that satisfies OSHA requirements. OSHA requirements also may be satisfied by certifying compliance with U.S. 29 C.F.R. §1928.53. As a result, the [ANSI/ROHVA] standard has been expanded to include certification to U.S. 29 C.F.R. §1928.53 as an alternative. Adding this alternative provides manufacturers with design flexibility while ensuring that ROV ROPS are certified to a nationally-recognized standard and comply with OSHA requirements.*"

Red, and therefore would not necessarily have had to be compliant with this. In addition, according to its manufacturer, the 2012 Big Red was built to comply with a different ROPS standard, in ANSI/OPEI B71.9 (2012)[14]. Obviously if the Honda Big Red ROPS meets the US ANSI/OPEI B71.9 (2012) ROPS performance criterion, then it is clear that that standard's load resistance requirement is significantly less demanding than the ISO 3471:2008(E) (ISO, 2008) requirement.

Lateral loading complies with ANSI/ROHVA 1-2011

Vertical loading reaches 88% of ANSI/ROHVA 1-2011 requirements after which test was stopped.

Figure 14: Honda Big Red loaded laterally and then vertically. Note failure of ROPS under vertical load in bottom frame

The ISO 3471:2008(E) standard specifies a Strength to Weight Ratio of 1.5 times the curb weight of a test vehicle or 22,240 N (5,000 lb) whichever is less. This test is the same as the Federal Motor Vehicle Safety Standard (FMVSS) 216 (earlier version) for passenger vehicles and pickups, and has since been revised to require a minimum of SWR of 3.0 as the SWR 1.5 ratio was found to be totally inadequate for occupant protection in rollover (Rechnitzer and Lane, 1994; Digges and Malliaris, 1998; Young et al., 2006; Grzebieta et al., 2007).

In Australia, currently there are no compliance requirements for SSVs or Quads to any such standards. Studies are required to determine if these ROPS standards are effective in real world rollover crashes or as with passenger vehicles a much higher SWR is required for ROPS occupant protection in SSV rollovers.

3. ROLLOVER CRASHWORTHINESS OVERALL RATING INDEX FOR THE 16 PRODUCTION TEST VEHICLES

The Rollover Crashworthiness Overall Rating Index is the third of the three major test components of the ATVAP Star rating system:

- Static Stability Tests
- Dynamic Stability Tests
- Rollover Crashworthiness Tests

The basis of the proposed Rollover Crashworthiness Overall Rating Index is the summation of the rating index values from the following five test results for each vehicle.

3.1 Points Ratings

Point scores for each test category are allocated as follows, with a total maximum of 25 points:

1. **Five points (5 points) are allocated to all vehicles automatically.** This is regardless of whether they are a Quad bike or an SSV. The intent of this allocation is that people do survive rollover crashes using these vehicles, e.g. Figure 3 in the case of a Quad-bike.

   In the case of Quad bikes, these can only receive 5 points as noted. Fitment of OPDs is not rated in terms of points currently as it is not possible to rate their relative effectiveness.

2. **ROPS**

   For SSVs five points (5 points) are allocated to a vehicle that has a four post (minimum) ROPS. This is regardless if the vehicle meets any of the US voluntary industry standards.

3. **For SSVs up to five points (5 points) are allocated to ROPS that meet the US ANSI/ROHVA 1-2011 ejection criteria and Zone restraint** with the additional proposed requirement of no displacement outside the width of the vehicle. Any excursion of the head or torso/shoulder outside the width results in no points allocated. For a situation where the vehicle meets the requirement but does not meet the Zone 1 to 4 and warning label requirement, 1 point is deducted for every instance the requirement is not met.

4. **For SSVs up to five points (5 points) are allocated to ROPS that meet the US ANSI/ROHVA 1-2011 (ISO Option) load criterion** – if the minimum load is not reached within the energy constraints of the standard in any one of the three loading directions the vehicle scores 0 points.

5. **For SSVs five bonus points (5 points)** are provided for SSVs that meet the US ANSI/ROHVA 1 (2011) requirements for: 3 point or harness seat belt (1 point); and a seat belt warning light which switches off when the seat belt is locked in (1 point); for

a seat belt audible alarm that is maintained for at least 5 minutes when a person is seated in the vehicle (1 point); and for a seat belt interlock system that is ignition or speed interlock based (2 points).

The total points for the Rollover Crashworthiness Rating Index is twenty five (25) and is similar to those proposed in the static stability rating (25) and dynamic handling rating (25).

3.2 The Rollover Crashworthiness Overall Rating Index

For the 16 production vehicles the weightings for each of the five categories and the total Rollover Crashworthiness Overall Rating Index is given in Table 3 and in bar chart form in Figure 15. The rating for the Prototype Quad bike is provided in Table 3.

The Rollover Crashworthiness Overall Rating Index has been calculated for a rider/ driver only, i.e. no loads were carried by any of the vehicles, and no OPD has been fitted to the work Quad bikes (Table 3 and Figure 15).

3.3 Observations from the Rollover Crashworthiness Overall Rating Index

All five SSV's with ROPS structures were assessed individually using the range of tests and criteria described above. Quad bikes were not assessed on an individual basis. Each Quad bike was awarded the baseline five points. From these index results given in Table 3 and Figure 15, the following observations are made.

The SSVs, all have notably higher overall indices with points from 15 to 21 (the Tomcar and John Deere received the highest rating), compared with 5 points for both the work Quad bikes and the recreational Quad bikes.

The Honda Big Red's performance in the ROPS vertical load test in which it did not sustain the full specified load in the variant of the ANSI/ROHVA 1-2011 standard (ISO Option) used , resulted in zero points allocated in this category, and hence the vehicle's lower performance compared to the Tomcar and John Deer SSVs.

In regards to the Quad bikes, the maximum rating these vehicles can potentially receive is an index of 5 if the straddle position is maintained with respect to the vehicle's design and 'separation' is the crashworthiness criterion adopted by the manufacturer.

Crashworthiness Overall Index driver/ rider only			Baseline rollover protection	ROPS fitted		Meets ANSI/ROHVA 1-2011 Ejection Criteria & Zone restraint		Meets ANSI/ROHVA 1-2011 ROPS Force Criteria		3 point or harness seat belt (1 pt), seat belt warning light (1 pt), seat belt 5 minute buzzer (1 pt), seat belt interlock (2 pts)		
Type	Make	Model	1. Rating		2. Rating		3. Rating		4. Rating		5. Rating	Total Index
SSV	Tomcar	TM2	5	Yes	5	Yes	5	Yes	5	Yes - Harness	1	21.0
SSV	Honda	MUV700 big red	5	Yes	5	Yes	5	No	0	Yes - 3 pt belts	1	16.0
SSV	John Deere	XUV825i	5	Yes	5	No - Zones 1, 2 & 4	2	Yes	5	Yes - belt and light	2	19.0
SSV	Yamaha	Rhino	5	Yes	5	No regarding excursion[2] No - Zones 2 & 3	0	Yes	5	Yes - 3 pt belts	1	16.0
SSV	Kubota	RTV500	5	Yes	5	No regarding excursion[1] No - Zone 1, 2 & 4 No helmet warning sticker	0	Yes	5	No - only 2 pt belt	0	15.0
Quad	CF Moto	CF500	5	No	0	No	0	No	0	No	0	5.0
Quad	Polaris	Sportsman 450H	5	No	0	No	0	No	0	No	0	5.0
Quad	Suzuki	Kingquad 400ASI	5	No	0	No	0	No	0	No	0	5.0
Quad	Honda	TRX500FM	5	No	0	No	0	No	0	No	0	5.0
Quad	Honda	TRX250	5	No	0	No	0	No	0	No	0	5.0
Quad	Yamaha	YFM450FAP Grizz	5	No	0	No	0	No	0	No	0	5.0
Quad	Kawasaki	KVF300	5	No	0	No	0	No	0	No	0	5.0
Quad	Kymco	MXU300	5	No	0	No	0	No	0	No	0	5.0
RQuad	Honda	TRX700XX	5	No	0	No	0	No	0	No	0	5.0
RQuad	Can-Am	DS90X	5	No	0	No	0	No	0	No	0	5.0
RQuad	Yamaha	YFM250R Raptor	5	No	0	No	0	No	0	No	0	5.0
Quad	Prototype		5	No	0	No	0	No	0	No	0	5.0
												Max 25

[1] Head outside vehicle width and pelvis slid on seat

[2] Head, torso, shoulder and elbow outside vehicle width

Table 3: Rollover Crashworthiness Overall Rating Index for the 17 vehicles, rider/driver only (i.e. no added loads).

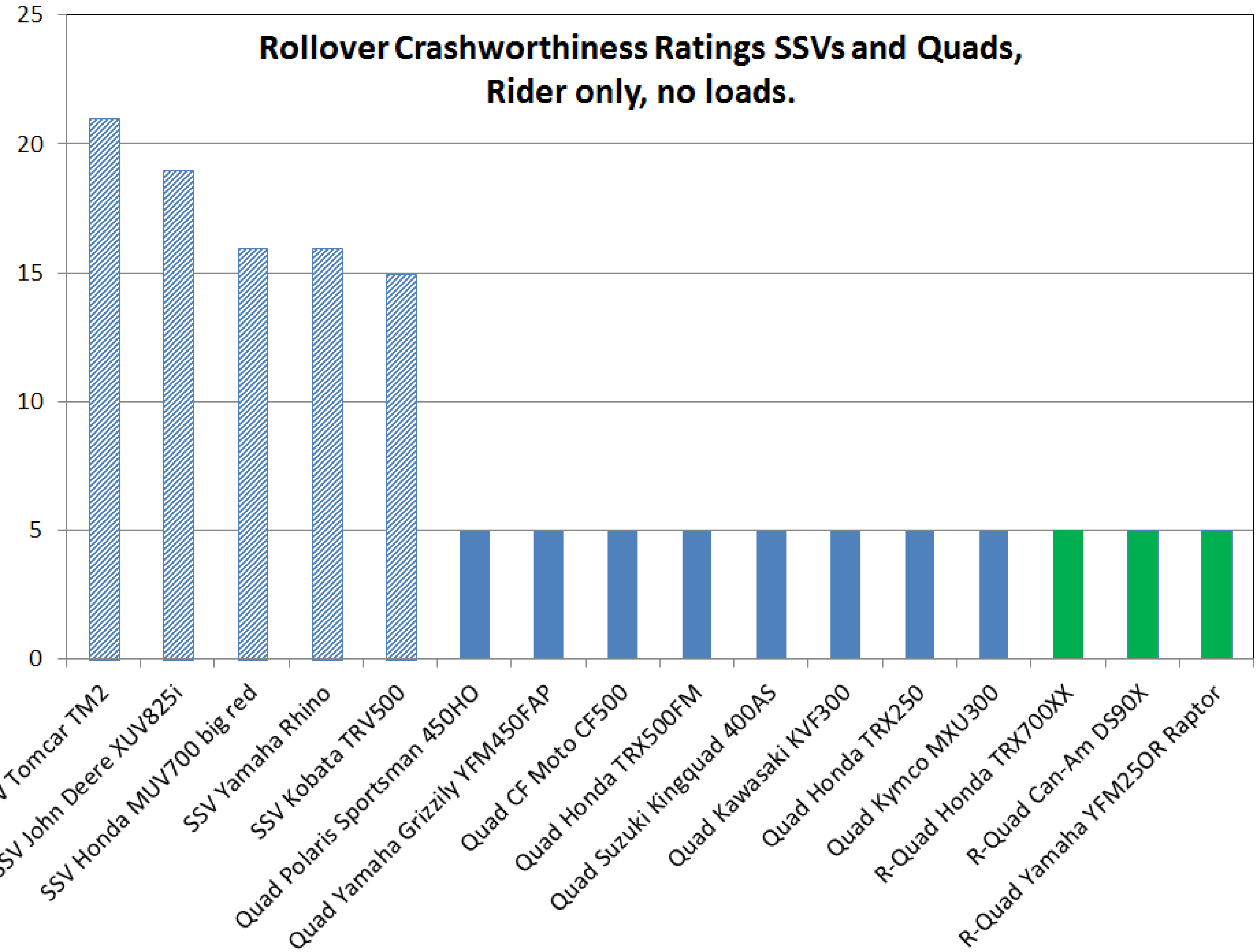

Figure 15: Rollover Crashworthiness Overall Rating Index for rider/ driver only.

4. CONCLUSIONS

The rollover crashworthiness test program provides the third arm of the assessment and rating of these Quad bikes and SSVs for rollover stability, handling and crashworthiness. It complements the static stability test program and the dynamic handling test program for the 17 vehicles.

The rollover crashworthiness test program consisted of 65 tests and SSV inspections focussing in three different areas, all relating to vehicle crashworthiness characteristics. These characteristics, ROPS, seatbelts, and occupant containment potentially reduce a driver/ rider's risk of harm in a rollover crash within the workplace environment.

4.1 Quad Fatalities and Injuries, Australia 2000 to 2012

1. The overarching conclusion from the review of the Australian Coronial Data for the period 2000 to 2012, is that rollover and subsequently being pinned and asphyxiated, often without other injury, are the primary injury mechanisms for Quad bike related fatalities on farms. These findings determined that the crashworthiness test program needs to be focussed on rollover of the Quad bikes and SSVs, with testing and ratings developed as presented in this report. The crashworthiness ratings will then be used with the ratings detailed in reports Part 1: Static Stability and Part 2: Dynamic Handling Test Results, to provide an overall focus on preventing rollovers and subsequent injury.

2. Fatal and non-fatal Quad bike related injuries obtained from various injury data collections indicate that the injury count for Quads/SSVs is currently estimated at approximately 1400 Emergency Department Presentations for Australia each year. Details of the mechanisms of how riders/ drivers/ passengers are injured and vehicle make/ model/ year are sketchy at best. This fundamental deficiency with data collection for Quad bikes (and SSVs) is still an impediment to advancing Quad bike safety and needs to be corrected in terms of hospital admissions and work related investigations.

4.2 Rollover crashworthiness of Quad bikes

1. At the start of this project, the project team considered that it would be possible - though challenging - to conduct testing which would distinguish between the rollover crashworthiness of different Quad bike models and SSVs. Through the exploratory rollover crashworthiness tests using the MATD as a surrogate vehicle operator, it became apparent (based on assumed test variability and the similarity of most Quad bikes) that it was unrealistic currently to discriminate the rollover crashworthiness between different Quad bike models, based on such rollover testing – however discrimination between these vehicle types (Quad bikes and SSVs) was realistic. In considering this, it was also recognised that there was little that differentiated the Quad bike models in terms of ground plane clearance in a rollover, and vehicle mass

might be the only substantial difference among Quad bikes. The exploratory tests did highlight the potential hazards that an operator would be exposed to when a Quad bike rolled, which were consistent with the review of fatal cases.

2. Further, it was also evident from such rollover testing, that for a rider of Quad bikes, due to the stochastic ('hit and miss') nature of severe injury risk and the large range of possible rollover permutations, it was unrealistic to continue with such tests for each Quad bike model for rating purposes.

3. Indeed it was concluded by the Authors that the term "Crashworthy Quad bike"[15] was essentially a contradiction in terms.[16] For this reason the Quad bike types were all rated equally for rollover crashworthiness, and all were assigned the 5 point baseline rating when assessing rollover crashworthiness protection. There are numerous instances where a rider has survived a rollover crash without any serious injury as illustrated by Van Ee et al. in Figure 3. Fundamentally Quad bikes where the rider straddles the vehicle and steers in the same way as a motorcycle via handle bars, do not and cannot satisfy the well-known principles of occupant protection in rollover - good containment, restraint of the occupant, impact management and crush prevention.

   The manufacturers' and industries' safety paradigm for Quad bikes is '*separation'* and Personal Protection Equipment (PPE), as with motorcycles. This strategy appears to work in a large number of instances albeit not in all the circumstances as evidence from the Coronial fatalities and hospitalisations data clearly demonstrate. Industries' '*separation'* safety paradigm for Quad bikes is not capable of meeting the 'Vision Zero' criteria required/ legislated in the workplace, i.e. death or serious injury that results in a permanent disability are not acceptable. Note however that death or serious injury that results in a permanent disability currently continues to occur with virtually all vehicles used in the workplace (i.e., trucks, tractors, machinery, passenger cars, motorcycles, etc.). However, as has been well established that the rate of fatalities for these vehicle types (including tractors) has decreased greatly due to advances in vehicle design, crash avoidance technology and crashworthiness amongst other factors.

4. Nor was it possible to discriminate Quad bike crashworthiness performance based on current real world crash information (in contrast to passenger vehicles, for example).

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[15] According to the Oxford Dictionary, the term "crashworthiness" is defined as "The degree to which a vehicle will protect its occupants from the effects of an accident." http://www.oxforddictionaries.com/definition/english/crashworthiness (accessed 14 August 2014)

[16] Note that the alternative view put by FCAI and industry is that a typical Quad bike 'protects' its occupant to some degree by a combination of: enabling rider separation from the vehicle, use of smooth and compliant outer surfaces, absence of large projections that may lacerate, impact or entangle the rider as he/she separates from the vehicle, and required warnings (under ANSI/SVIA 1 (2010)) for use of helmet, eye protection and protective clothing.

This is due to the absence of make/model/year (MMY) crash involvement injury data and exposure data for Quad bikes and SSVs. This fundamental deficiency with data collection for Quad bikes (and SSVs) where MMY is noted is still an impediment to advancing Quad bike safety. For Quad bikes, this leaves rollover crash prevention as the primary control mechanism to prevent injury in rollover, with the fitment of OPDs as a secondary measure that could reduce injury risk in some circumstances in the workplace, with the understanding that injury risk may also increase in some crash types. As with motorcycles, the safety crashworthiness basis for Quad bikes is separation. It needs to be recognised that Quad bike riders are in this same category of 'unprotected vulnerable road users'. Similarly if increased crash protection is a key performance requirement then, as with motorcycles, different vehicle types which offer such protection as part of their design need to be considered and substituted instead (e.g. SSVs), assuming that the latter meet the other functional requirements of the specific work tasks of interest.

4.3 Rollover Crashworthiness of SSVs

1. In contrast to the Quad bikes, the SSVs do adhere in general to rollover crashworthiness principles, in that they are fitted with ROPS, seatbelts and various degrees of containment measures which combine to keep the occupants within a protected space. As the effectiveness of such designs in terms of severe injury prevention can vary widely, it is possible to discriminate and rate SSVs, as a first step.

2. The SSVs were rated for rollover crashworthiness against the containment, occupant retention and ROPS requirements of the ANSI/ROHVA 1-2011 standard for SSVs (which comes into force in the USA for 2014 model SSV vehicles).

3. SSVs with a well-designed rollover protection and containment system provide greater potential rollover crashworthiness in comparison to Quad bikes even when the Quad bikes are fitted with an OPD. This is on the condition that SSV drivers and passengers are restrained with an appropriate seat belt, namely a 3 point lap sash belt or a 4 or 5 point harness, and wear an approved helmet.

   Containment refers to maintaining the driver and any occupants within the vehicle during a typical rollover such that partial or full ejection does not occur. The requirements for such containment have been well established with passenger and other vehicles and include the need for side doors and in the case of SSVs side meshing similar to the Honda Big Red vehicle. For children, the use of appropriate child seats properly restrained within the SSV should also be used.

4. The SSV ROPS for three vehicles met the US ANSI/ROHVA 1-2011 voluntary industry standard. The Honda Big Red, while not meeting all the ROPS load requirements of the standard, did meet the lateral load requirement and 88% of the vertical load before the ROPS could no longer sustain any increase in load. It was subsequently discovered that the Honda Big Red met the US ANSI/OPEI B71.9 (2012) standard which requires a

ROPS Strength to Weight Ratio (SWR) of only 1.5, which has been found by the Authors to be totally inadequate for occupant protection in rollover in regards to passenger vehicles.

5. In Australia, currently there are no compliance requirements for SSVs or Quad bikes to any standards. Studies are required to determine if any of the ROPS standards cited in this report are effective in real world rollover crashes or, as with passenger vehicles, a much higher SWR is required for ROPS occupant protection in rollover.

6. All five SSVs had seat belts fitted. The Tomcar offered 4 point harness seat belts whereas the Kubota only offered 2 point seat belts. The John Deere offered a seat belt warning light which extinguished when the seat belt was engaged, but only on the driver side. The Yamaha Rhino also offered a seat belt warning light but it did not switch off when the seat belt was engaged. None of the SSVs offered an audible seat belt warning system or seat belt assurance system (interlocks).

4.4 Effectiveness of Operator Protective Devices (OPDs)

1. Retrofitting an OPD has been encouraged by a number of Quad bike safety stakeholders and is currently being considered by regulators. The rollover crash tests with the Honda TRX500 indicate that such devices do increase survivability and 'crawl out' space (clearance) and change crush loads applied to the operator under certain rollover circumstances. The baseline rollover crash tests demonstrated how the full weight of the Quad bike without an OPD could rest on top of the rider in lateral, rearward and forward pitch rolls, whereas when the vehicle was fitted with an OPD the vehicle's full weight did not load or rest on the rider;

2. The performance of the Quadbar in terms of rollover crash harm minimisation appeared superior in some aspects to the Lifeguard in a low velocity, low height, rearward pitch scenario. When the Quad bike was pitched rearward from a higher height of 1,500 mm (measured from the lower edge of the tilt table) the Quadbar deformed such that it reduced the CG rising and thus to some extent alleviated the situation presented in Figure 6, while at the same time providing survival/ crawl out space and maintaining the rear of the vehicle above the rider.

3. In the Quad bike tests, the rider was at risk of neck and head injuries in the lateral and forward pitch direction rollover tests. The Coronial data has revealed that seven farm workers received cervical spine fractures or dislocations and three farmers had cervical spinal cord injury. There were two thoraco-lumbar vertebral fractures. There were no lumber or thoracic spinal cord injuries.

4. There is a concern that the Quadbar may impart a load to the head, neck, or back similar to the scenario depicted in Figure 4. For the Quad bikes, the contact ground load tests for the Quad bike on its side or up-side-down, showed that that point loads on a person under the Quad bike, would exceed the mechanical asphyxia load

criterion of 50kg, with and without OPDs. However, OPDs would likely reduce the risk due to increasing survival space for the inverted position, but not for a Quad bike on its side.

5. The OPD may offer the conscious operator or rescuer an opportunity to self-extract (crawl out) or extract the pinned operator by increasing survival space. Overall, the Authors consider that the addition of an OPD will likely result in a net benefit in terms of reducing harm to workplace Quad bike riders involved in a rollover crash. This is based on the assumptions that (a) Quad bike overturns in the workplace environment typically occur at low speeds; (b) based on limited testing, and (c) the Authors are currently unaware of any injuries from OPDs that have occurred in the field.

   The important qualifiers here are:

   a. A 'fitness for purpose assessment' be carried out first and the opportunity to substitute a well-designed SSV, for example, for a Quad bike should be considered. If an SSV is not 'Fit For Purpose', then an OPD is an engineering control that may improve Quad bike safety in the workplace.

   b. In some crash events such OPD devices could result in injury – rather than prevent it[3];

   c. It is essential that close monitoring and ongoing evaluation of the field performance of OPDs is required.

   d. Improved, more in-depth and uniform Quad bike and SSV accident data collection forms and procedures be put in place at state and federal levels, to enable monitoring of the relevant details of Quad bike and SSV incidents, including OPD and ROPS/ seat belt effects (both positive and negative).

4.5 The Rollover Crashworthiness Ratings

These provide a points rating out of 25 points, of the Author's assessment of the rollover crashworthiness of the tested vehicles for the workplace environment, based on the rollover tests, evaluation against the US ANSI/ROHVA standard and fundamental crashworthiness principles of rider/occupant protection in rollovers. It was noted that:

1. The SSVs all have notably higher overall rating (see Table 3 and Figure 15) with points from 15 to 21, with the Tomcar and John Deere receiving the highest rating, and compare with 5 points for both the Work Quad bikes and Recreational Quad Bikes.
2. In regards to the current Quad bike designs, the maximum rating these vehicles can potentially receive is an index of 5 if the straddle position is maintained with respect to the vehicle's design and no rider protection is fitted to the vehicles, i.e. a ROPS. The work Quad bikes were all indexed at 5 points.

3. In contrast to the current Quad bike designs, well designed SSVs offer superior rollover crash protection in a typical farming environment, i.e. they are fitted with ROPS, seatbelts and various degrees of containment measures which combine to keep the occupants within a protected space. This does not rule out that Quad bike designs cannot be improved in future to provide similar levels of crashworthiness safety to well designed SSVs. This is provided that three point (or harness) seatbelts and helmets are worn and other occupant lateral restraints are fitted and in place.
4. The results from the rollover crashworthiness tests provide sufficient discrimination in the range of vehicles tested (Quad bikes and SSVs) to use as a basis for the rollover safety rating system.
5. The real-world validation and ongoing improvement and refinement of such ratings and Quad bike and SSV safety design, will further depend on the ongoing, proper, systematic collection of real world crash data involving Quad bikes and SSVs, including MMY and exposure data.

Signed:

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6. Appendix 1: Retention Device Inspections to ANSI/ROHVA 1-2011

From Crashlab Crashworthiness Test Reports.

Test Vehicle: TOMCAR
Test Specimen Number: ____________________
Date: 20/03/2014
Inspected by: David Hicks

	Activity	Seating Position: Left	Middle	Right (Driver)
Seat Belt				
1	Each Seating Position has a minimum Type 2 (3-Point) Occupant Restraint (ANSI/ROVA 1:11.1)	Yes: 4 Point Harness	N/A	Yes: 4 Point Harness
2	If Yes, does the Occupant Restraint meet or exceed SAE J2292 (i.e. warning label displayed)	Cannot determine		Cannot determine
Seat Belt Reminder				
3	Is a lighted seat belt reminder fitted	No		No
4	Does the reminder remain active for at least 8 seconds after the ignition switch is turned on	N/A		N/A
5	Is the light visible to the seated operator	N/A		N/A
Zone 1				
6	Is a Leg/Foot barrier fitted	Yes		Yes
7	Type of barrier (Doors, Raised Entry or other Suitable Devices)	Raised Entry Doors		Raised Entry Doors
8	Does the barrier encompass the area defined in Figure 1	Yes		Yes
9	Does the barrier interfere with vehicle operation or affect visibility	No	N/A	No
10	Can barrier withstand a horizontal side force of 222N at the centroid of area defined by Point P	Yes		Yes
Zone 2				
11	Is a Shoulder/Hip barrier fitted	Yes		Yes
12	Type of barrier (Doors, Nets or other Suitable Devices)	Door		Door
13	Does the barrier encompass the area defined in Figure 2	Yes		Yes
14	Does the barrier interfere with vehicle operation or affect visibility	No	N/A	No
Zone 3				
15	Is a Arm/Hand barrier fitted	Yes		Yes
16	Type of barrier (Doors, Nets or other Suitable Devices)	Door Waist Barrier		Door Waist Barrier
17	Does the barrier encompass the area defined in Figure 3	Yes		Yes
18	Does the barrier interfere with vehicle operation or affect visibility	No	N/A	No
Zone 4				
19	Is a Head/Neck barrier fitted	Yes		Yes
20	Type of barrier (Head Rest, Nets or other Suitable Devices)	Head Rest Door		Head Rest Door
21	Do these devices compromise the visibility and mobility a seatbelted, helmet wearing rider	No	N/A	No
Operator Warnings Labels				
22	Use of Seat Belts recommended		Yes	
23	Use of Helmets recommended		Yes	
24	Occupant being in the seated position recommended		Yes	

Other/Comments

Seat Belt conformance not labelled
Passenger Hand Hold

Test Vehicle: Honda BigRed 700
Test Specimen Number: ____________________
Date: 20/03/2014
Inspected by: David Hicks

		Seating Position		
	Activity	**Left (Driver)**	**Middle**	**Right**
Seat Belt				
1	Each Seating Position has a minimum Type 2 (3-Point) Occupant Restraint (ANSI/ROVA 1:11.1)	Yes: 3 Point Harness		Yes: 3 Point Harness
2	If Yes, does the Occupant Restraint meet or exceed SAE J2292 (i.e. warning label displayed)	Cannot Determine		Cannot Determine
Seat Belt Reminder				
3	Is a lighted seat belt reminder fitted	No	No	No
4	Does the reminder remain active for at least 8 seconds after the ignition switch is turned on	N/A	N/A	N/A
5	Is the light visible to the seated operator	N/A	N/A	N/A
Zone 1				
6	Is a Leg/Foot barrier fitted	Yes		Yes
7	Type of barrier (Doors, Raised Entry or other Suitable Devices)	Door		Door
8	Does the barrier encompass the area defined in Figure 1	Yes		Yes
9	Does the barrier interfere with vehicle operation or affect visibility	No	N/A	No
10	Can barrier withstand a horizontal side force of 222N at the centroid of area defined by Point P			
Zone 2				
11	Is a Shoulder/Hip barrier fitted	Yes		Yes
12	Type of barrier (Doors, Nets or other Suitable Devices)	Net		Net
13	Does the barrier encompass the area defined in Figure 2	Yes		Yes
14	Does the barrier interfere with vehicle operation or affect visibility	No	N/A	No
Zone 3				
15	Is a Arm/Hand barrier fitted	Yes		Yes
16	Type of barrier (Doors, Nets or other Suitable Devices)	Net		Net
		Hip Barrier		Hip Barrier
17	Does the barrier encompass the area defined in Figure 3	Yes		Yes
18	Does the barrier interfere with vehicle operation or affect visibility	No	N/A	No
Zone 4				
19	Is a Head/Neck barrier fitted	Yes		Yes
20	Type of barrier (Head Rest, Nets or other Suitable Devices)	Head Rest		Head Rest
		Net		Net
21	Do these devices compromise the visibility and mobility a seatbelted, helmet wearing rider	No	N/A	No
Operator Warnings Labels				
22	Use of Seat Belts recommended		Yes	
23	Use of Helmets recommended		Yes	
24	Occupant being in the seated position recommended		Yes	
Other/Comments				
	Paseenger Hand Hold			

Test Vehicle: John Deere Gator
Test Specimen Number: TS57209
Date: 20/03/2014
Inspected by: David Hicks

		Seating Position		
	Activity	**Left (Driver)**	**Middle**	**Right**
Seat Belt				
1	Each Seating Position has a minimum Type 2 (3-Point) Occupant Restraint (ANSI/ROVA 1:11.1)	Yes: 3 Point Harness	N/A	Yes: 3 Point Harness
2	If Yes, does the Occupant Restraint meet or exceed SAE J2292 (i.e. warning label displayed)	Yes: SAE J386		Yes: SAE J386
Seat Belt Reminder				
3	Is a lighted seat belt reminder fitted	Yes		No
4	Does the reminder remain active for at least 8 seconds after the ignition switch is turned on	Yes		N/A
5	Is the light visible to the seated operator	Yes		N/A
Zone 1				
6	Is a Leg/Foot barrier fitted	No		No
7	Type of barrier (Doors, Raised Entry or other Suitable Devices)	N/A		N/A
8	Does the barrier encompass the area defined in Figure 1	N/A		N/A
9	Does the barrier interfere with vehicle operation or affect visibility	N/A	N/A	N/A
10	Can barrier withstand a horizontal side force of 222N at the centroid of area defined by Point P	N/A		N/A
Zone 2				
11	Is a Shoulder/Hip barrier fitted	No		No
12	Type of barrier (Doors, Nets or other Suitable Devices)	N/A		N/A
13	Does the barrier encompass the area defined in Figure 2	N/A		N/A
14	Does the barrier interfere with vehicle operation or affect visibility	N/A	N/A	N/A
Zone 3				
15	Is a Arm/Hand barrier fitted	Yes		Yes
16	Type of barrier (Doors, Nets or other Suitable Devices)	Waist Barrier		Waist Barrier
17	Does the barrier encompass the area defined in Figure 3	No		No
18	Does the barrier interfere with vehicle operation or affect visibility	No	N/A	No
Zone 4				
19	Is a Head/Neck barrier fitted	No		No
20	Type of barrier (Head Rest, Nets or other Suitable Devices)	N/A		N/A
21	Do these devices compromise the visibility and mobility a seatbelted, helmet wearing rider	N/A	N/A	N/A
Operator Warnings Labels				
22	Use of Seat Belts recommended		Yes	
23	Use of Helmets recommended		Yes	
24	Occupant being in the seated position recommended		Yes	
Other/Comments				
	Passenger Hand Hold			

Test Vehicle: Kubota
Test Specimen Number: ____________________
Date: ____________________
Inspected by: ____________________

	Activity	Seating Position Left (Driver)	Middle	Right
Seat Belt				
1	Each Seating Position has a minimum Type 2 (3-Point) Occupant Restraint (ANSI/ROVA 1:11.1)	No: 2 Point Harness	No	No: 2 Point Harness
2	If Yes, does the Occupant Restraint meet or exceed SAE J2292 (i.e. warning label displayed)	No	No	No
Seat Belt Reminder				
3	Is a lighted seat belt reminder fitted	No	No	No
4	Does the reminder remain active for at least 8 seconds after the ignition switch is turned on	N/A		N/A
5	Is the light visible to the seated operator	N/A		N/A
Zone 1				
6	Is a Leg/Foot barrier fitted	No		No
7	Type of barrier (Doors, Raised Entry or other Suitable Devices)	N/A		N/A
8	Does the barrier encompass the area defined in Figure 1	N/A		N/A
9	Does the barrier interfere with vehicle operation or affect visibility	N/A	N/A	N/A
10	Can barrier withstand a horizontal side force of 222N at the centroid of area defined by Point P	N/A		N/A
Zone 2				
11	Is a Shoulder/Hip barrier fitted	No		No
12	Type of barrier (Doors, Nets or other Suitable Devices)	N/A		N/A
13	Does the barrier encompass the area defined in Figure 2	N/A		N/A
14	Does the barrier interfere with vehicle operation or affect visibility	N/A	N/A	N/A
Zone 3				
15	Is a Arm/Hand barrier fitted	Yes		Yes
16	Type of barrier (Doors, Nets or other Suitable Devices)	Waist Barrier		Waist Barrier
17	Does the barrier encompass the area defined in Figure 3	No		No
18	Does the barrier interfere with vehicle operation or affect visibility	No	N/A	No
Zone 4				
19	Is a Head/Neck barrier fitted	No		No
20	Type of barrier (Head Rest, Nets or other Suitable Devices)	N/A		N/A
21	Do these devices compromise the visibility and mobility a seatbelted, helmet wearing rider	N/A	N/A	N/A
Operator Warnings Labels				
22	Use of Seat Belts recommended		Yes	
23	Use of Helmets recommended		No	
24	Occupant being in the seated position recommended		Yes	
Other/Comments				
	Passenger Hand Hold Fitted			

Test Vehicle: Yamaha Rhino 700
Test Specimen Number: ____________________
Date: 28/03/2014
Inspected by: David Hicks

	Activity	Seating Position Left (Driver)	Middle	Right
Seat Belt				
1	Each Seating Position has a minimum Type 2 (3-Point) Occupant Restraint (ANSI/ROVA 1:11.1)	Yes: 3 Point Harness	N/A	Yes: 3 Point Harness
2	If Yes, does the Occupant Restraint meet or exceed SAE J2292 (i.e. warning label displayed)	Yes: SAE J386		Yes: SAE J386
Seat Belt Reminder				
3	Is a lighted seat belt reminder fitted	Yes		Yes
4	Does the reminder remain active for at least 8 seconds after the ignition switch is turned on	Yes		Yes
5	Is the light visible to the seated operator	Yes		Yes
Zone 1				
6	Is a Leg/Foot barrier fitted	Yes		Y/N
7	Type of barrier (Doors, Raised Entry or other Suitable Devices)	Door		Door
8	Does the barrier encompass the area defined in Figure 1	Yes		Yes
9	Does the barrier interfere with vehicle operation or affect visibility	No	N/A	No
10	Can barrier withstand a horizontal sied force of 222N at the centroid of area defined by Point P	Yes		Yes
Zone 2				
11	Is a Shoulder/Hip barrier fitted	No		No
12	Type of barrier (Doors, Nets or other Suitable Devices)	N/A		N/A
13	Does the barrier encompass the area defined in Figure 2	N/A		N/A
14	Does the barrier interfere with vehicle operation or affect visibility	N/A	N/A	N/A
Zone 3				
15	Is a Arm/Hand barrier fitted	Yes		Yes
16	Type of barrier (Doors, Nets or other Suitable Devices)	Waist Barrier		Waist Barrier
17	Does the barrier encompass the area defined in Figure 3	No		No
18	Does the barrier interfere with vehicle operation or affect visibility	N/A	N/A	N/A
Zone 4				
19	Is a Head/Neck barrier fitted	Yes		Yes
20	Type of barrier (Head Rest, Nets or other Suitable Devices)	Head Rest		Head Rest
21	Do these devices compromise the visibility and mobility a seatbelted, helmet wearing rider	No	N/A	No
Operator Warnings Labels				
22	Use of Seat Belts recommended		Yes	
23	Use of Helmets recommended		Yes	
24	Occupant being in the seated position recommended		Yes	
Other/Comments				
	Two Passenger Hand Hold			

7. ATTACHMENT 1: Crashlab Special Report SR2014/003, Quad Bike Performance Project, Crashworthiness Testing

Crashlab Special Report SR2014/004, Quad Bike Performance Project, Crashworthiness Testing, and Appendices A, B, C, D, E.

Appendix A – Test matrix
Appendix B – Instrument response data
(Separate attachment as file is very large)
Appendix C – Test specimen details
Appendix D – Test photographs
Appendix E – Instrument details

Special Report SR2014/003

Quad bike performance project
Crashworthiness testing

Client: Transport and Road Safety (TARS) Research
1st Floor West Wing, Old Main Building (K15)
University of New South Wales (UNSW)
Sydney, NSW 2052

Client's Reference: Quad bike performance project – Crashworthiness

Test Specification: Work as directed by TARS, based upon ANSI/ROHVA 1-2011

Tests: 65 Tests

Date of Tests: 12th March 2014 to 20th May 2014

Prepared by: ______________________ Date: 27JUN14

Drew Sherry, BE (Mech)
Test Engineer

Checked & Issued By: ______________________ Date: 27 Jun 14

Ross Dal Nevo, BE (Mech)
Manager Crashlab®

Table of Contents

1 Test summary

1.1 Introduction

This report presents the results of a test program studying occupant protection and crashworthiness performance characteristics of a number of commercially available quad bikes and side-by-side vehicles.

The test program consisted of four different test configurations;

- Quad bike ground contact load
- Side-by-side vehicle occupant retention
- Side-by-side vehicle Roll-Over Protective Structure loading
- Vehicle and occupant rollover test

In addition to these four vehicle test configurations, a number of research tests were carried out to investigate the chest loading characteristics of the Motorcycle Anthropomorphic Test Device (MATD).

The quad bike ground contact load test consisted of measuring the mass of a quad bike at all contact points with a flat level ground plane. The vehicle was tested upright and inverted and on its side with various Crush Protection Devices fitted.

The Side-by-Side Vehicle (SSV) occupant retention tests consisted of securing an Anthropomorphic Test Device (ATD) in the front outboard seating position of an SSV using the vehicle's occupant restraint system. The vehicle was then rolled laterally to a defined angle and the amount of ATD excursion outside of the vehicle width was recorded.

The Side-by-Side Vehicle Roll-Over Protective Structure (ROPS) structure load tests consisted of applying a lateral load followed by a vertical load then a longitudinal load to the vehicle ROPS whilst recording the deflection and noting the structural integrity.

The vehicle and occupant rollover tests consisted of positioning a Motorcycle ATD (MATD) in the operator's position of a quad bike or side-by-side vehicle, tilting the vehicle to an angle at which rollover would occur and releasing the vehicle to rollover. MATD injury data and damage were recorded.

The tests described in this report were conducted at Crashlab, Huntingwood, NSW, Australia.

The tests were conducted between 12th of March 2014 and 20th of May 2014 by Crashlab and Transport and Road Safety (TARS) Research personnel.

1.2 Definitions

For the purpose of this report the following definitions are used:

Quad Bike: A four wheeled motorised vehicle fitted with a seat that is straddled by the operator and handle bars for steering control.

Side-by-Side Vehicle (SSV): A four wheeled motorised vehicle with conventional bucket seats or bench seat that allows two people to sit in the vehicle next to each other. The vehicle steering control is operated by a steering wheel.

Vehicle: Either a Quad bike or SSV

Crush Protection Device (CPD): An after-market device designed to be fitted to a quad bike to reduce the crush injuries that may be experienced by a vehicle operator during a rollover event.

Rollover Protective Structure (ROPS): An integral structure fitted to a vehicle to reduce the crush injuries that may be experienced by a vehicle operator during a rollover event.

1.3 Program Objectives

The objectives of the Quad bike performance project (Crashworthiness) test program were to:

- Determine the *ground contact loads* at the ground contact points of a commercially available quad bike with and without a CPD fitted, with the vehicle positioned upright, on its side and inverted
- Determine the *occupant retention characteristics* of a number of commercially available SSVs when the vehicle is laterally rolled to an angle of 45°
- Determine the *Roll-Over Protective Structure integrity* of a number of commercially available SSVs when loaded laterally, vertically and longitudinally
- Determine the *occupant injury values* of an operator during a vehicle rollover event for a commercially available quad bike with and without a CPD fitted
- Determine the *occupant injury values* of an operator during a vehicle rollover event for a number of commercially available SSVs
- Determine the *vehicle and occupant kinematic characteristics* during a vehicle rollover event for a commercially available quad bike with and without a CPD fitted
- Determine the *vehicle and occupant kinematic characteristics* during a vehicle rollover event for a number of commercially available SSVs

2 Method

2.1 Test method - Quad bike ground contact load

The quad bike ground contact load test was conducted by measuring the gravitational load of each ground contact point of the vehicle. The vehicle was positioned on a smooth flat ground plane and permitted to stabilise in a natural position without external support. All vehicle contact points with the ground were marked. The vehicle was then raised, load cells of equal height placed under each marked contact point and the vehicle lowered onto the load cells.

The ground contact forces were measured with the vehicle in the following orientations:

- Upright, all four wheels in contact with the ground
- On left side (rolled approximately 90˚)
- Inverted (rolled approximately 180˚)
- Inverted and rolled partially to left side (rolled between 100˚ and 170˚) – only measured if the vehicle would stabilise in position without external support

The vehicle was tested with the following CPDs fitted:

- Nil (standard vehicle)
- Quadbar
- Lifeguard

Details of the CPDs are located in Appendix C.

The vehicle was tested at a mass equal to the vehicle unladen mass (unoccupied with all fluid reservoirs filled to nominal capacity including fuel, and with all standard equipment), plus the mass of the CPD if fitted.

The vehicle tyres were inflated to the minimum tyre pressure recommended by the vehicle manufacturer.

Figure 1 – Quad bike ground contact force test in progress

Results are located in Table 2
Photographs of the tests are located in Appendix D
Details of the vehicle are located in Appendix C

2.2 Test method – Side-by-side vehicle occupant retention

The Side-by-side vehicle occupant retention tests are based on those specified in American National Standard for Recreational Off-Highway Vehicles ANSI/ROHVA 1-2011[1], Section 11 Occupant Retention Systems.

The tests consisted of placing an Anthropomorphic Test Device (ATD) in the front outboard seating position of an SSV and restraining the ATD by fastening the vehicle's occupant restraint system. The vehicle was placed on a single axis tilt table which tilted the vehicle about its longitudinal axis. The tilt table rolled each vehicle to an angle of 45° measured on the vehicle chassis. Each vehicle was rolled towards both the driver side and passenger side with the ATD always located in the 'low side' of the vehicle.

Two vertical-longitudinal planes were projected along side the vehicle located 127mm and 178mm outside the widest part of the vehicle. The performance requirements of ANSI/ROHVA 1-2011 state that the torso of the ATD must not extend beyond the plane 127mm outside the vehicle width and that the hands and arm of the ATD must not extend beyond the plane 178mm outside the vehicle width.

The ATD used in this testing was a Hybrid III 50th percentile Motorcycle ATD (MATD). The MATD was positioned in the seat with the pelvis centred on the seat centreline and the back upright and in contact with seat back. The MATD is equipped with gripping hands that were adjusted to grip the steering wheel when in the driver's seat. When positioned in the passenger seat the hands gripped the provided hand grips. If no hand grips were present the hand was rested on the dummy's thigh without gripping any part of the vehicle. A number of vehicles were also tested with the ATD positioned in the passenger seat with both hands resting on the dummy's thighs without gripping any part of the vehicle.

Figure 2 – Side-by-Side Vehicle occupant retention test in progress

Test results are located in Table 3

Photographs of the tests are located in Appendix D

Vehicle details are located in Appendix C

2.3 Test method – Side-by-Side Vehicle Roll-Over Protective Structure

The Side by side vehicle Roll-Over Protective Structure (ROPS) tests are based on those specified in American National Standard for Recreational Off-Highway Vehicles ANSI/ROHVA 1-2011[1], Section 10 Roll Over Protective Structure (ROPS).

Each vehicle ROPS was tested by applying a uni-axial load to the top of the structure sequentially in three different directions. The load directions in order are:

- Lateral (from driver side towards passenger side of vehicle)
- Vertical (from top of vehicle towards bottom)
- Longitudinal (from front of vehicle towards rear)

The lateral and longitudinal loads were applied through a load distribution device by a single hydraulic cylinder attached to a rigid test fixture. The load application point was determined in accordance with ANSI/ROHVA 1-2011. The vertical load was applied through two hydraulic cylinders, one located on each side of the vehicle. The two cylinders pulled down on a flat rigid steel load plate that was positioned in accordance with ANSI/ROHVA 1-2011 and covered the top surface of the ROPS.

The vehicle chassis was rigidly mounted to the test fixture structure close to the vehicle suspension pickup points.

The magnitude of the applied forces were calculated using formulas supplied in ANSI/ROHVA 1-2011 as listed below.

- Lateral force (N) = 6m
- Lateral energy (J) = $13000(m/10^4)^{1.25}$
- Vertical force (N) = 19.61m
- Longitudinal force (N) = 4.8m

Where m = maximum vehicle laden mass (kg)

When applying the lateral force, the load was applied to meet the theoretical required lateral energy for an elastically deforming structure, up to twice the required lateral force. The actual energy applied was calculated post test.

The performance requirements of ANSI/ROVHA 1-2011 that were chosen to be met are:

- The ROPS must meet or exceed the lateral, longitudinal and vertical force and energy requirements (For this test series a concession to meeting the lateral energy requirement was permitted if the ROPS was loaded with more than twice the required lateral force)
- The ROPS must not break away from the vehicle
- The ROPS must not fail or collapse

During the tests the following parameters were recorded:

- Applied load (kN) for each hydraulic ram
- Structure deflection (mm) co-liner with direction of applied load

The following data is reported:

- Total applied load (kN)
- Structure deflection (mm)
- Applied energy (J) for lateral load application
- Permanent deflection/ damage to ROPS structure

Figure 3 – SSV Roll-Over Protective Structure (ROPS) lateral pull test in progress

Test results are located in Table 4

Photographs of the test are located in Appendix D

2.4 Test method – Vehicle and occupant rollover test

The vehicle and occupant rollover tests consisted rolling a vehicle with an ATD located in the operator position off a tilt table onto a simulated ground surface.

Each vehicle was positioned on a single axis tilt table with the tyres located 1000mm from the 'lowered' edge of the tilt table. The vehicle brakes were applied and the tyres located on expanded mesh anti-slip plates so the vehicle would tip over rather than slide down the tilt table surface. The vehicle and ATD were tethered to the table to prevent premature vehicle tip over. The tilt table was slowly raised from horizontal to the angle at which the vehicle alone would rollover. When the desired angle was reached, the tethers securing the vehicle and ATD were simultaneously released, allowing the vehicle to rollover under the force of gravity.

A Motorcycle Anthropomorphic Test Device (MATD) conforming with the requirements of ISO 13232 Motorcycles – Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles[2] was positioned in the operator seating location of each vehicle. When seated upon a quad bike, the MATD was positioned with its back vertical in both longitudinal and lateral planes and in accordance with ISO 13232, (hands and feet on the vehicle controls, elbows bent 10°, head angle horizontal). When seated in an SSV the MATD was positioned with the pelvis rearward and centred on the seat pan, the back firmly against the seat backrest, the hands gripping the steering wheel, the head angle horizontal and the vehicle restraint system fastened.

The MATD was clothed in form fitting cotton stretch shorts and a waterproof single piece motorcycle rain suit. The MATD was also fitted with leather shoes equivalent to those specified in MIL-S13192 revP. A Bell Custom 500 open face helmet was fitted to the MATD head and positioned using the alignment tool specified in ISO 13232.

The ground surface that the vehicle was rolled onto consisted of a raised floor constructed from two layers of timber pallets with a sheet of 100mm thick polystyrene (Clark Rubber part number: 75717) placed on top. The polystyrene was covered with 10mm thick industrial rubber floor matting. The height of the raised floor coincided approximately with the height of the 'lowered' edge of the tilt table when raised to the test angles.

A single model of quad bike was tested in the following roll configurations:

- Lateral roll
- Rearward pitch
- Forward pitch

The quad bike was test with the following Crush Protection Devices (CPDs) fitted

- Nil (standard vehicle)
- Quadbar
- Lifeguard

Two models of SSV were tested in the following roll configuration:

- Lateral roll (towards driver side)

The SSVs were not fitted with any additional CPDs, however both vehicles had integral ROPS.

The vehicles were tested at a mass equal to the vehicle unladen mass, plus the mass of the MATD and any fitted CPD. The vehicle tyres were inflated to the minimum tyre pressure recommended by the vehicle manufacturer.

The MATD was supplied and calibrated prior to testing by Dynamic Research, Inc. The dummy was instrumented to the requirements of ISO 13232 with the following parameters recorded:

- Head acceleration (9channels)
- Chest displacement (4 channels)
- Upper neck force (3 channels)
- Upper neck moment (3 channels)
- Chest acceleration (3 channels)
- Pelvis acceleration (3 channels)
- Lumbar force (3 channels)
- Lumbar moment (3 channels)
- Upper femur force (1channel) left
- Upper femur moment (3 channels) left
- Upper femur force (1 channel) right
- Upper femur moment (3 channels) right

In addition to instruments, the MATD was fitted with the following frangible components:

- Femur (left and right)
- Tibia (left and right)
- Knee varus valgus (left and right shear pin)
- Knee torsion (left and right shear pin)

Damage to any frangible components was recorded after the test and the damaged component replaced.

The recorded MATD instrument data from each test was processed in accordance with ISO 13232 using software provide by Dynamic Research, Inc. with the following data reported:

- Maximum Abbreviated Injury Scale (AIS) injury
- Probability of fatality
- Probability of AIS 1+ head injury
- Probability of AIS 1+ neck injury
- Probability of AIS 1+ chest injury
- Probability of AIS 1+ leg injury
- Head Injury Criterion (HIC)

Figure 4 – Rollover test with occupant, test in progress

Test results are located in Table 5

Photographs of the tests are located in Appendix D

Vehicle details are located in Appendix C

2.5 Tilt table

A tilt table was used in two of the test configurations of this program to tilt a vehicle about a single axis from horizontal to a know angle.

The tilt table comprised a lower frame which was rigidly fixed to the floor. The upper frame is attached to the lower frame through two co-linear pin joints, which allow for a tilt angle arc range of between 0° to 80° from horizontal. The upper frame of the table is lifted by two hydraulic rams with flow control valves to achieve a quasi-static tilt rate of less than 1° per second. The upper surface of the tilt table was fitted with a form-ply decking to enable technical officers access around a vehicle when on the table.

Expanded mesh anti-slip plates were fixed to the tilt table upper surface between the vehicle tyres and form-ply decking to reduce the likelihood of the vehicle sliding down the tilt table surface.

Photographs of the test fixture are located in Appendix D

2.6 Hydraulic test fixture

A hydraulic test fixture was used in the SSV ROPS test to load the vehicle ROPS to the required force whilst restricting the vehicle chassis from movement.

The hydraulic test fixture consisted of a rigid steel test fixture to which a hydraulic cylinder was attached. Two steel rails with adjustable vehicle mounting stands were securely bolted to the floor in front of the test fixture.

For the lateral and longitudinal tests, each vehicle chassis was securely fixed to the mounting stands. A single hydraulic cylinder was aligned with the desired load application point. A load cell was fitted between the Load Distribution Device (LDD) on the vehicle ROPS and the hydraulic cylinder. A string potentiometer was fitted between the test fixture rigid frame and the vehicle ROPS at the location of the LDD to measure the lateral or longitudinal deflection.

For the vertical ROPS test a steel frame was located under the vehicle supporting the vehicle chassis close to the location of the suspension mounts. The steel frame was positioned on the test fixture mounting stands and the vehicle was securely fixed in place. A rigid steel load plate was suspended above the ROPS and aligned in accordance with the requirements of ANSI/ROHVA 1-2011. One hydraulic cylinder was positioned vertically on either side of the vehicle between the steel frame and the load plate. The hydraulic cylinders were operated on the same hydraulic circuit which permitted them to apply equal forces to the load plate. The cylinders were positioned so that the load was applied symmetrically about the longitudinal centreline of the load plate. A load cell was fitted between each hydraulic cylinder and the load plate. A string potentiometer was located vertically between the ROPS and the vehicle structure to measure the vertical deflection of the ROPS. To initiate the test, the load plate was lowered onto the ROPS. The hydraulic cylinders then pulled the load plate vertically down in unison to the required load. It should be noted that the gravitational force that the load plate imparted on the vehicle ROPS was taken into account when calculating the required load to be applied by each hydraulic cylinder.

Photographs of the test fixture are located in Appendix D

2.7 Test vehicles

The test program encompassed six vehicles which can be separated into two vehicle types.

One of the vehicles was a quad bike fitted with front and rear load racks:

- Honda Foreman TRX500

Five of the vehicles were larger two-seat Side-by-side vehicles (SSVs) fitted with rear cargo trays:

- Honda Big Red MUV700
- Kubota RTV500
- John Deere Gator XUV825i
- Yamaha Rhino 700
- Tomcar TM2

Vehicle details are contained in Appendix C, vehicle photographs are contained in Appendix D.

2.8 Crush Protection Devices (CPDs)

Two Crush Protection Devices (CPDs) were including in the test program to determine the effect on ground contact load and during vehicle rollover. Details of the CPDs are included in Appendix C.

Each of the CPDs was fitted to the Honda TRX500 quad bike.

2.9 Test matrix

The test matrix consisted of 53 individual tests as tabled below.

			Number of tests			
Vehicle make	Vehicle model	Vehicle type	Ground contact force	Occupant retention	ROPS	Rollover test with occupant
Honda	Big red MUV700	SSV	-	3	2	-
Kubota	RTV500	SSV	-	4	3	-
John Deere	Gator XUV825i	SSV	-	3	6	-
Yamaha	Rhino 700	SSV	-	3	3	1
Tomcar	TM2	SSV	-	3	3	1
Honda	TRX500	Quad bike	8	-	-	10
					Ground contact force total	*8*
					Occupant retention total	*16*
					ROPS total	*17*
					Rollover test with occupant total	*12*
					Total	***53***

Table 1- Test Matrix

For the full list of test configurations and test run numbers see Tables 2 to 6 and Appendix A.

In addition to the 53 tests covered in this test program, the results of 12 development and research tests are included. These tests consist of 5 vehicle and occupant rollover tests using the Honda TRX500 and MATD, and 7 chest loading tests conducted with the MATD. The results for these tests are located in Tables 5 and 6.

2.10 Instrumentation and data acquisition

The ground contact load tests utilised four calibrated single axis vehicle load scales with digital display.

The applied force in the ROPS tests was measured with either one or two load cells and the deflection was measured with a string potentiometer. The data was recorded with a TDAS Pro data acquisition system. The data acquisition rate was approximately 1Hz with a live readout to monitor the test in progress.

For the vehicle and occupant rollover tests the MATD was fitted with internal accelerometers and load cells to the requirements of ISO 13232. The data was recorded with the MATD internal data acquisition system at a rate of 10000Hz. The data was processed in accordance with ISO 13232 using software provided by Dynamic Research, Inc.

Details of the instruments are contained in Appendix E.

3 Test Results

Table 2 – Test results, Quad bike ground contact load

Vehicle make	Vehicle model	Specimen number	CPD fitted	Vehicle orientation	Load contact point on ground	Load (kg)	Total load (kg)
Honda	TRX500	TS57200	Nil	Vehicle up-right on four wheels	Left front wheel	77.0	293.0
					Right front wheel	73.0	
					Left rear wheel	68.0	
					Right rear wheel	75.0	
Honda	TRX500	TS57200	Nil	Vehicle on left side	Left front wheel	114.0	293.0
					Left rear wheel	72.5	
					Left front wheel guard	42.5	
					Left rear wheel guard	64.0	
Honda	TRX500	TS57200	Nil	Vehicle inverted	Left front handlebar	87.5	293.0
					Right front handlebar	131.5	
					Rear load rack	74.0	
Honda	TRX500	TS57200	Lifeguard	Vehicle up-right on four wheels	Left front wheel	76.5	308.0
					Right front wheel	71.5	
					Left rear wheel	76.0	
					Right rear wheel	84.0	
Honda	TRX500	TS57200	Lifeguard	Vehicle on left side	Left front wheel	113.5	309.0
					Left rear wheel	78.5	
					Left front wheel guard	36.0	
					Left rear wheel guard	81.0	
Honda	TRX500	TS57200	Lifeguard	Vehicle inverted	Left front handlebar	96.0	308.0
					Right front handlebar	133.0	
					Front load rack	31.5	
					Lifeguard	47.5	
Honda	TRX500	TS57200	Lifeguard	Vehicle inverted and rolled partially towards left side	Left front load rack	139.5	308.5
					Headlight housing	54.5	
					Lifeguard	114.5	
Honda	TRX500	TS57200	Quadbar	Vehicle up-right on four wheels	Left front wheel	77.0	302.5
					Right front wheel	71.0	
					Left rear wheel	73.0	
					Right rear wheel	81.5	
Honda	TRX500	TS57200	Quadbar	Vehicle on left side	Left front wheel	118.0	302.5
					Left rear wheel	63.5	
					Left front wheel guard	31.5	
					Left rear wheel guard	89.5	
Honda	TRX500	TS57200	Quadbar	Vehicle inverted	Headlight housing	274.5	301.5
					Quadbar	27.0	
Honda	TRX500	TS57200	Quadbar	Vehicle inverted and rolled partially towards left side	Left front load rack	146.5	303.0
					Headlight housing	66.0	
					Quadbar	90.5	

Table 3 – Test results, Side-by-Side Vehicle occupant retention

Vehicle make	Vehicle model	Specimen number	Test number	Test date	Tilt direction	Setup	Does ATD torso extend more than 127mm outside vehicle width	Does ATD hands or arms extend more than 178mm outside vehicle width	Does ATD extend beyond vehicle width	Comments
Honda	Big red MUV700	TS57210	G140053	01-Apr-14	Right (passenger side)	Right hand on A-pillar hand hold, left hand gripping centre of seat. Net in place	No	No	No	ATD restrained. Wrist lightly touched net but did not deflect it.
			G140054	01-Apr-14	Left (driver side)	Hands on steering wheel. Net in place	No	No	No	ATD restrained. ATD elbow, shoulder and head touched net.
			G140055	01-Apr-14	Left (driver side)	Hands on steering wheel. Net removed	No	No	No	ATD restrained. More ATD lateral movement than G140055.
Kubota	RTV500	TS57208	G140056	01-Apr-14	Right (passenger side)	Right hand on A-pillar hand hold, left hand gripping centre of seat. ATD yawed and leant forward to reach hand hold	No	No	No	ATD restrained, pelvis slid on seat
			G140057	01-Apr-14	Right (passenger side)	Right hand on waist height hand grip/bar, left hand holding seat	No	No	Yes. ATD head approx 137mm outside vehicle width	Pelvis slid on seat
			G140058	01-Apr-14	Right (passenger side)	Hands on lap	No	No	Yes. ATD head approx 50mm outside vehicle width	Pelvis slid on seat, right elbow braced against waist height bar.
			G140059	04-Apr-14	Left (driver side)	Hands on steering wheel	No	No	Yes. ATD head approx 50mm outside vehicle width	Both hands came off steering wheel
John Deere	Gator XUV825i	TS57209	G140060	04-Apr-14	Right (passenger side)	Right hand on A-pillar hand hold, left hand gripping centre console	No	No	No	ATD restrained
			G140061	04-Apr-14	Right (passenger side)	Hands on lap	No	No	No	ATD restrained
			G140062	04-Apr-14	Left (driver side)	Hands on steering wheel	No	No	No	ATD restrained
Yamaha	Rhino 700	TS57207	G140063	04-Apr-14	Right (passenger side)	Right hand on A-pillar hand hold, left hand gripping centre hand hold	No	No	Yes. ATD elbow approx 92mm outside vehicle width	ATD restrained
			G140064	04-Apr-14	Right (passenger side)	Hands on lap	No	No	Yes. ATD head approx 127mm outside vehicle width. ATD torso/shoulder approx 82mm outside vehicle body width	
			G140065	04-Apr-14	Left (driver side)	Hands on steering wheel	No	No	Yes. ATD torso/shoulder approx 25mm outside vehicle width	
Tomcar	TM2	TS59881	G140066	07-Apr-14	Left (passenger side)	Left hand on A-pillar hand hold, right hand on lap	No	No	No	ATD restrained
			G140067	07-Apr-14	Left (passenger side)	Hands on lap	No	No	No	ATD restrained
			G140068	07-Apr-14	Right (driver side)	Hands on steering wheel	No	No	No	ATD restrained

Table 4 – Test results, Side-by-Side Vehicle Roll-Over Protective Structure loading

Vehicle make	Vehicle model	Specimen number	Maximum vehicle mass (kg)	Test number	Test date	ROPS test direction	Calculated required pull force (N)	Maximum achieved pull force (N)	Calculated required pull energy (J)	Maximum achieved pull energy (J)	Maximum ROPS deflection (mm)	Permanent ROPS deflection after test (mm)	Comments
John Deere	Gator XUV825i	TS57209	1411	G140089	01-May-14	Lateral pull	8466	8678	1124	755	151	35	Energy criteria not met (loading repeated in test G1400093)
John Deere	Gator XUV825i	TS57209	1411	G140090	02-May-14	Vertical pull	27670	27905	-	-	27	2	
John Deere	Gator XUV825i	TS57209	1411	G140091	05-May-14	Longitudinal pull	6773	7154	-	-	39	0	
Yamaha	Rhino 700	TS57207	920	G140092	06-May-14	Lateral pull	5520	11971	659	684	109	30	
John Deere	Gator XUV825i	TS57209	1411	G140093	06-May-14	Lateral pull	8466	11142	1124	1883	242	108	
Kubota	RTV500	TS57208	1051	G140094	07-May-14	Lateral pull	6306	12442	778	994	130	43	
Tomcar	TM2	TS59881	1166	G140095	07-May-14	Lateral pull	6996	14592	886	198	23	4	Double force criteria met, (energy criteria not met)
Honda	Big red MUV700	TS57210	1414	G140096	08-May-14	Lateral pull	8484	9854	1127	1573	242	117	
Honda	Big red MUV700	TS57210	1414	G140097	08-May-14	Vertical pull	27729	24326	-	-	121	82	Load criteria not met. ROPS yielded (significant additional deflection without significant increase in load)
Tomcar	TM2	TS59881	1166	G140098	09-May-14	Vertical pull	22865	23433	-	-	11	4	
Yamaha	Rhino 700	TS57207	920	G140099	09-May-14	Vertical pull	18041	18626	-	-	8	1	
Kubota	RTV500	TS57208	1051	G140100	12-May-14	Vertical pull	20610	20928	-	-	17	2	
Kubota	RTV500	TS57208	1051	G140101	12-May-14	Longitudinal pull	5045	5222	-	-	25	0	
Yamaha	Rhino 700	TS57207	920	G140102	13-May-14	Longitudinal pull	4416	4463	-	-	23	4	
Tomcar	TM2	TS59881	1166	G140103	13-May-14	Longitudinal pull	5597	5630	-	-	8	1	
John Deere	Gator XUV825i	TS57209	1411	G140104	14-May-14	Vertical pull	27670	28135	-	-	32	4	
John Deere	Gator XUV825i	TS57209	1411	G140106	14-May-14	Longitudinal pull	6773	6879	-	-	39	3	

Data traces of ROPS tests are located in Appendix B of this report

Table 5 – Test results, Vehicle and occupant rollover

Test number	G140075	G140076	G140077	G140078	G140079	G140080	G140082	G140085	G140087	G140088
Vehicle make	Honda	Honda	Honda	Honda	Honda	Honda	Honda	Honda	Honda	Honda
Vehicle model	TRX500	TRX500	TRX500	TRX500	TRX500	TRX500	TRX500	TRX500	TRX500	TRX500
Specimen number	TS59641	TS59641	TS59641	TS59641	TS59641	TS59641	TS59641	TS59641	TS59641	TS59641
Test date	15-Apr-14	15-Apr-14	15-Apr-14	15-Apr-14	16-Apr-14	16-Apr-14	16-Apr-14	17-Apr-14	17-Apr-14	17-Apr-14
Tilt direction	Lateral roll (right)	Lateral roll (right)	Lateral roll (right)	Rear pitch	Rear pitch	Rear pitch	Forward pitch	Forward pitch	Forward pitch	Forward pitch
Protection device fitted	Nil	Lifeguard	Quadbar	Quadbar	Lifeguard	Nil	Lifeguard	Quadbar	Lifeguard	Nil
ATD	MATD	MATD	MATD	MATD	MATD	MATD	MATD	MATD (HIII neck)	MATD (HIII neck)	MATD (HIII neck)
Roll distance from tilt table edge (mm)	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Tilt table angle at release (degrees)	40	40	40	51	51	51	50	50	50	50
Test surface	100mm polystyrene on 2 pallets, covered with rubber mat	100mm polystyrene on 2 pallets, covered with rubber mat	100mm polystyrene on 2 pallets, covered with rubber mat	100mm polystyrene on 2 pallets, covered with rubber mat	100mm polystyrene on 2 pallets, covered with rubber mat	100mm polystyrene on 2 pallets, covered with rubber mat	100mm polystyrene on 2 pallets, covered with rubber mat	100mm polystyrene on 2 pallets, covered with rubber mat	100mm polystyrene on 2 pallets, covered with rubber mat	100mm polystyrene on 2 pallets, covered with rubber mat
ATD damage	1 finger, 1 thumb broken right hand	Nil	Nil	Nil	Nil	2 fingers broken right hand	MATD neck broken, 3 fingers broken left hand	Nil	Nil	Nil
Vehicle damage	Handlebar bent	Handlebar bent	Handlebar bent	Quadbar bent	Front rack bent, dents in lifeguard plastic ribs	Minor front & rear rack deformation	Dents in lifeguard plastic ribs	Nil	Lifeguard crack at base	Nil
Vehicle rest position	Inverted	Inverted, rear supported by Lifeguard	On right side	On rear/Quadbar, tyres in contact with tilt table	On wheels	Inverted	On wheels	Inverted, rear supported by Quadbar	On right side	Inverted
Maximum AIS injury	0	0	0	0	0	0	0	0	0	0
Probability of fatality	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
Probability of AIS Head injury	0.027	0.030	0.033	0.038	0.079	0.008	0.005	0.004	0.003	0.004
Probability of AIS Neck injury	0.002	0.002	0.002	0.000	0.000	0.000	0.005	0.170	0.098	0.067
Probability of AIS Chest injury	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.003
Probability of AIS Leg injury	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Head Injury Criterion, HIC	167	173	179	188	180	99	78	84	83	87
Gambit	0.25	0.24	0.25	0.29	0.37	0.19	0.17	0.14	0.15	0.15
Neck Injury Index, NII	1.81	1.82	1.8	0.49	0.75	0.91	2.05	3.77	3.35	3.1
Neck Fz compression (kN)	-3.53	-3.26	-3.6	-0.68	-0.38	-0.78	-4.32	-7.94	-7.05	-6.54
Neck Mx (Nm)	89.2	82.6	85.6	9.5	6.4	7.8	41.0	24.2	33.7	44.3
Neck My, extension (Nm)	-35.0	-47.0	-36.5	-10.5	-35.6	-45.7	-4.9	-32.7	-35.8	-15.8
Neck My, flexion (Nm)	15.4	13.8	16.0	20.5	44.2	39.8	66.4	193.2	168.7	167.5
Upper sternum deflection x (mm)	-8.2	-11.9	-8.5	-2.7	-2.8	-3.8	-3.4	-21.5	-8.6	-19.9
Upper sternum deflection y (mm)	20.2	20.3	18.4	2.0	5.4	2.0	12.8	18.4	8.6	20.6
Upper sternum VC (m/s)	0.02	0.03	0.01	0	0	0.01	0	0.08	0.02	0.06
Lower sternum deflection x (mm)	-4.4	-7.5	-6.9	-2.2	-1.6	-2.1	-0.1	-24.2	-11.9	-20.2
Lower sternum deflection y (mm)	19.3	19.5	18.1	1.9	5.2	2.0	11.2	19.5	8.6	21.6
Lower sternum VC (m/s)	0.01	0.01	0.01	0	0	0	0	0.1	0.03	0.06
Lumbar Fz compression (kN)	-1.69	-1.71	-1.51	-0.53	-0.56	-1.73	-1.71	-2.66	-2.24	-2.25
Lumbar Mx (Nm)	80.6	85.4	83.6	21.3	11.9	12.8	24.3	30.9	45.2	40.1
Lumbar My, extension (Nm)	-218.4	-217.1	-232.8	-202.9	-42.1	-44.8	-135.9	*-758.46	-435.8	-624.6
Lumbar My, flexion (Nm)	550.5	503.8	575.6	560.5	592.4	*780.1	658.6	166.3	325.0	144.1
Frangible femur fracture	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Frangible tibia fracture	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Frangible knee pin fracture (varus valgus)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Frangible knee pin fracture (torsional)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
						*Lumbar signal clipped		*Lumbar signal clipped		

Table 5 cont. – Test results, Vehicle and occupant rollover

Test number	G140107	G140108	latroll_00	latroll_01	latroll_02	latroll_03	rearpitch_01
Vehicle make	Tomcar	Yamaha	Honda	Honda	Honda	Honda	Honda
Vehicle model	TM-2	Rhino	TRX500	TRX500	TRX500	TRX500	TRX500
Specimen number	TS59881	TS57207	TS59641	TS59641	TS59641	TS59641	TS59641
Test date	20-May-14	20-May-14	12-Mar-14	13-Mar-14	14-Mar-14	14-Mar-14	14-Mar-14
Tilt direction	Lateral roll (right)	Lateral roll (left)	Lateral roll (right)	Lateral roll (right)	Lateral roll (right)	Lateral roll (right)	Rear pitch
Protection device fitted	Vehicle ROPS	Vehicle ROPS	Nil	Nil	Nil, 60kg spray tank	Quadbar	Quadbar
ATD	MATD (HIII neck)	MATD (HIII neck)	MATD	MATD (HIII neck)	MATD (HIII neck)	MATD (HIII neck)	MATD (HIII neck)
Roll distance from tilt table edge (mm)	1000	1000	1500	1500	1500	1500	1500
Tilt table angle at release (degrees)	45	40	43	43	43	43	51
Test surface	100mm polystyrene on 2 pallets, covered with rubber mat	100mm polystyrene on 2 pallets, covered with rubber mat	100mm polystyrene covered with rubber mat	Ply board on 3 pallets, covered with rubber mat	100mm polystyrene on 2 pallets, covered with rubber mat	100mm polystyrene on 2 pallets, covered with rubber mat	100mm polystyrene on 2 pallets, covered with rubber mat
ATD damage	Nil	Nil	MATD neck broken	Right shoulder clavicle broken, left knee pin broken	Left knee pin broken	Nil	Nil
Vehicle damage	ROPS laterally deformed approx 35mm	Nil	Nil	Nil	Nil	Handlebar bent	Front rack bent, Quadbar bent
Vehicle rest position	On ROPS/RHS, tyres in contact with tilt table	On ROPS/LHS, tyres in contact with tilt table	On wheels	On right side (1 1/4roll)	On wheels	On wheels	On right side
Maximum AIS injury	0	0	0	2	2	0	0
Probability of fatality	0.000	0.000	0.000	0.051	0.009	0.000	0.000
Probability of AIS Head injury	0.031	0.011	0.052	0.745	*	0.027	0.016
Probability of AIS Neck injury	0.000	0.000	0.003	0.034	*	0.022	0.003
Probability of AIS Chest injury	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Probability of AIS Leg injury	0.000	0.000	0.000	1.000	1.000	0.000	0.000
Head Injury Criterion, HIC	125	71	205	622	*	145	140
Gambit	0.28	0.21	0.31	0.76	*	0.27	0.23
Neck Injury Index, NII	0.63	0.94	1.93	2.74	2.18	2.53	1.91
Neck Fz compression (kN)	-0.78	-1.91	-4.07	-5.77	-3.1	-3.58	-1.74
Neck Mx (Nm)	34.8	55.8	55.7	83.5	97.6	119.9	26.9
Neck My, extension (Nm)	-5.7	-3.7	-26.5	-20.0	-41.0	-45.7	-106.4
Neck My, flexion (Nm)	7.8	12.9	14.4	12.7	24.6	22.0	52.2
Upper sternum deflection x (mm)	-3.0	-0.4	-14.8	-10.8	-4.7	-13.7	-5.8
Upper sternum deflection y (mm)	4.3	13.2	27.4	24.3	23.9	29.6	10.5
Upper sternum VC (m/s)	0	0	0.05	0.01	0.01	0.04	0.01
Lower sternum deflection x (mm)	-2.3	-0.1	-7.2	-6.9	-2.9	-8.5	-3.6
Lower sternum deflection y (mm)	4.4	13.2	25.3	23.8	23.5	29.7	9.7
Lower sternum VC (m/s)	0	0	0.01	0.01	0	0.02	0
Lumbar Fz compression (kN)	-0.16	-0.6	-1.74	-2.24	-2.6	-1.5	-1.63
Lumbar Mx (Nm)	16.1	34.5	39.4	91.5	106.8	42.0	22.7
Lumbar My, extension (Nm)	-67.0	-105.6	-200.0	-463.7	-359.3	-96.7	-141.0
Lumbar My, flexion (Nm)	96.5	255.7	*652.29	654.7	661.2	738.5	*758.25
Frangible femur fracture	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Frangible tibia fracture	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Frangible knee pin fracture (varus valgus)	Nil	Nil	Nil	1	1	Nil	Nil
Frangible knee pin fracture (torsional)	Nil	Nil	Nil	Nil	Nil	Nil	Nil
			*Lumbar signal clipped		*ATD connector failure resulted in loss of a1,a2,a3 head data. ATD released after vehicle.		*Lumbar signal clipped

Data traces and results for each test are located in Appendix B of this report

Table 6 – Test results MATD chest compression

Test number	Chest 1	Chest 2	Chest 3	Chest 4	Chest 5	Chest 6	Chest 7
Test date	13-Mar-14	13-Mar-14	13-Mar-14	13-Mar-14	13-Mar-14	13-Mar-14	13-Mar-14
ATD	MATD	MATD	MATD	MATD	MATD	MATD	MATD
Test setup	ATD lying on back, object placed on chest mid sternum	ATD lying on back, object dropped on chest mid sternum	ATD lying on back, object dropped on chest mid sternum	ATD lying on back, object dropped on chest mid sternum	ATD lying on back, object dropped on chest mid sternum	ATD lying on back, rear rack of inverted quad bike dropped on chest mid sternum, timber board on chest to distribute load, handlebars in contact with ground used as pivot point	ATD lying on back, rear rack of inverted quad bike dropped on chest mid sternum, timber board on chest to distribute load, handlebars in contact with ground used as pivot point
Ground surface	100mm polystyrene sheet on concrete	100mm polystyrene sheet on concrete	100mm polystyrene sheet on concrete	100mm polystyrene sheet on concrete	100mm polystyrene sheet on concrete	100mm polystyrene sheet on concrete	100mm polystyrene sheet on concrete
Object dropped on chest	Steel mass	Steel mass	Steel mass	Steel mass	Steel mass	Rear rack of Honda TRX500	Rear rack of Honda TRX500
Object mass (kg)	30	30	30	30	30	74 (approx)	74 (approx)
Drop height (mm)	0	250	500	750	1000	300	500
Maximum upper chest deflection x (mm)	3.74	20.04	32.04	39.97	46.06	17.74	27.83
Maximum upper chest deflection y (mm)	0.33	5.56	20.45	7.15	26.96	9.8	7.49
Maximum lower chest deflection x (mm)	4.19	20.49	29.26	35.94	38.68	16.62	25.23
Maximum lower chest deflection y (mm)	0.46	6.83	24.08	10.14	30.04	10.97	8.19

4 Discussion

4.1 Quad bike ground contact load

The ground contact load of a Honda TRX500 was measured with a Quadbar CPD fitted, a Lifeguard CPD fitted and a without a CPD.

In the upright condition with all four wheels on the ground, the individual wheel masses were similar. The maximum variance between wheel loads was 17% when the vehicle was fitted with the Lifeguard CPD.

When rolled 90° the quad bike rested on the same four contact points irrespective of if a CPD was fitted or not. The ground contact points were the left front wheel, left rear wheel, left front plastic wheel guard, left rear plastic wheel guard. The front left wheel applied the greatest load typically accounting for one third of the vehicle mass. The load split front to rear however was almost equal.

When inverted the vehicle had ground contact points at the front of the vehicle, typically the handlebars or headlight shroud, and a single point at the rear of the vehicle, either the CPD if fitted or the rear load rack when the CPD was not fitted. Typically a large portion of the vehicle mass was applied through the ground contact points at the front of the vehicle. Without a CPD fitted 75% of the vehicle mass was applied to the ground through the two handlebars with only 25% applied through the rear load rack. With a CPD fitted the proportion of load applied through the rear vehicle contact point reduced further. The Lifeguard applied 16% of the load with the handlebars and front load rack applying the remaining load. The Quadbar applied less than 10% of the load with the headlight shroud at the front of the quad bike applying more than 90% of the load at a single contact point.

With a CPD fitted the vehicle could be placed in a stable position when inverted and rolled partially to one side. In this position the corner of the front load rack made contact with the ground. The front load rack contact point of the vehicle applied the highest load to the ground. The load applied by the CPD contact point at the rear of the vehicle accounted for approximately one third of the total mass in this configuration for both CPDs.

4.2 Side-by-side vehicle occupant retention

Each side-by-side vehicle was tested rolled towards both the driver and passenger sides. When seated in the driver position the MATD gripped onto the steering wheel. When positioned in the passenger seat the vehicle was typically tested with MATD gripping the available handhold and also with the hands located on the dummy lap.

All vehicles met the performance requirements of ANSI/ROHVA 1–2011. In no tests did the hands or arms of the dummy extend beyond 178mm of the vehicle width. Similarly in no tests did the torso of the dummy extend beyond 127mm of the vehicle width.

The Honda Big red, fitted with a three-point lap sash belt, fully contained the dummy in all tests. This vehicle was also fitted with a retractable side net that could be fastened to provide additional occupant restraint from lateral movement.

The Kubota RTV500, fitted with a two point lap belt, allowed the dummy to extend beyond the vehicle width in a number of tests. When tested in the passenger seat the dummy head extended 137mm outside the vehicle width.

The John Deere Gator, fitted with a three point lap sash belt, fully contained the dummy within the vehicle width in all tests.

The Yamaha Rhino, fitted with a three point lap sash belt, allowed the dummy to extend beyond the vehicle width in all tests. When tested in the driver seat the dummy shoulder extended 25mm outside the vehicle width. When tested in the passenger seat, holding onto the provided grips, the dummy elbow extended 92mm outside the vehicle width.

The Tomcar TM2 was fitted with a four point harness. The dummy was contained within the vehicle width in all tests.

4.3 Side-by-Side Vehicle Roll-Over Protective Structure loading

For the SSV ROPS load tests each vehicle was individually loaded laterally then vertically then longitudinally. The magnitude of the required loads were calculated based on vehicle mass, as such the Honda Big red and John Deere Gator were subjected to the greatest loads, followed by the Tomcar TM2, Kubota RTV500 then Yamaha Rhino.

The Honda Big red ROPS significantly yielded when vertically loaded and did not meet the load requirements of ANSI/ROHVA 1–2011. All other vehicles met the force requirements of ANSI/ROHVA 1–2011.

The Honda Big red ROPS met and exceeded the lateral force requirements (by 16%) and energy requirements (by 40%). The maximum ROPS deflection during the lateral pull test was 242mm with a permanent deflection of 117mm. The ROPS did not meet the vertical load requirement. The applied force reached 88% of the required load at which point the ROPS structure began to yield and significantly deform. Once the structure had begun to yield, the ROPS continued to deform with a reduction in applied lateral force. The test was stopped with significant permanent deflection and buckling to ROPS.

The John Deere Gator was initially tested through one complete load cycle (lateral, vertical, longitudinal) meeting all load requirements. The ROPS however was not loaded enough in the lateral test to meet the lateral energy requirement. Subsequently the vehicle ROPS was subjected to a second complete load cycle meeting all force and energy requirements. In the lateral test the ROPS exceeded the lateral force requirements (by 31%) and energy requirement (by 67%). The maximum ROPS deflection during the lateral pull test was 242mm with a permanent deflection of 108mm. The ROPS structure met the vertical load requirement exhibiting a maximum deflection of 32mm with a permanent vertical deflection of 4mm. The ROPS structure met the longitudinal load requirement with a maximum deflection of 39mm and a permanent longitudinal deflection of 3mm.

The Kubota RTV500 ROPS met and exceeded the force and energy requirements of ANSI/ROHVA 1-2011 without failure. In the lateral test the ROPS exceeded the lateral force requirements by 97% and the energy requirement by 28%. The maximum ROPS deflection during the lateral pull test was 130mm with a permanent deflection of 43mm. The ROPS met the vertical load requirement exhibiting a maximum deflection of 17mm with a permanent vertical deflection of 2mm. The ROPS met the longitudinal load requirement with a maximum deflection of 25mm without any permanent longitudinal deflection.

The Yamaha Rhino ROPS met and exceeded the force and energy requirements of ANSI/ROHVA 1-2011 without failure. In the lateral test the ROPS exceeded the lateral force requirement by a little more than double and the energy requirement by 4%. The maximum ROPS deflection during the lateral pull test was 109mm with a permanent deflection of 30mm. The ROPS met the vertical load requirement exhibiting a maximum deflection of 8mm with a permanent vertical deflection of 1mm. The ROPS met the longitudinal load requirement with a maximum deflection of 23mm and a permanent longitudinal deflection of 4mm.

The Tomcar TM2 ROPS met and exceeded the force requirements of ANSI/ROHVA 1-2011 without failure. Due to the stiff ROPS construction and relatively minor deflection exhibited when the lateral load was applied, the energy absorbed by the ROPS was 22% of the figure required by ANSI/ROHVA 2011-1. The energy absorbed by the ROPS failed to meet the requirements of ANSI/ROHVA 2011-1 however for this test series a concession to meeting the lateral energy requirement was permitted if the ROPS was loaded with more than twice the required lateral force without failure. The Tomcar TM2 ROPS exceeded the lateral force requirement by more than double without failure. The maximum ROPS deflection during the lateral pull test was 23mm with a permanent deflection of 4mm. The ROPS met the vertical load requirement exhibiting a maximum deflection of 11mm with a permanent vertical deflection of 4mm. The ROPS met the longitudinal load requirement with a maximum deflection of 8mm and a permanent longitudinal deflection of 1mm.

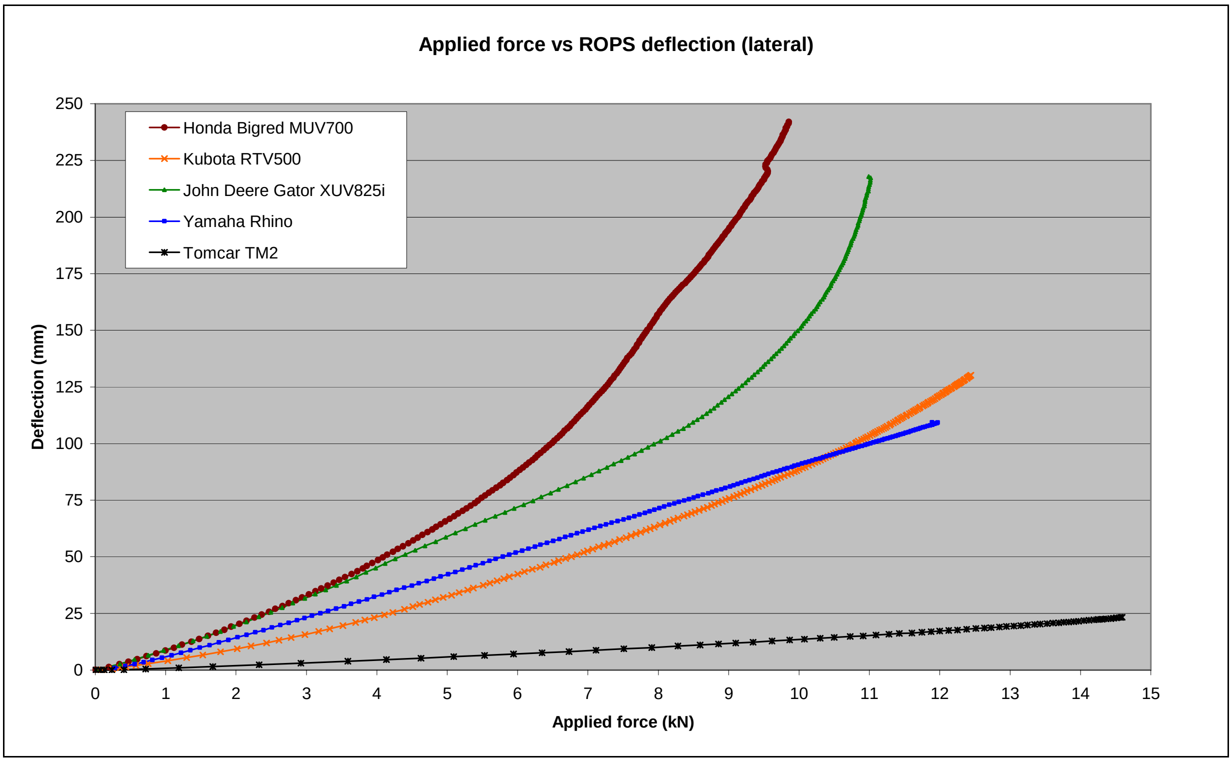

Figure 5: ROPS load test (lateral), Applied force vs ROPS deflection

Figure 5 shows the lateral load applied to each ROPS structure vs deflection.

A shallow gradient represents a stiffer ROPS structure that is more resistant to deformation whereas a steep gradient characterises a structure with greater deformation for the same applied force. The Tomcar TM2 ROPS was the stiffest, whereas the Honda Big red ROPS offered the least resistance to load.

A relatively linear trace represents a structure that exhibits predominantly elastic deformation with little permanent deformation whereas a curved trace shows a structure that experiences significant permanent deformation. The Yamaha Rhino and Tomcar TM2 exhibited the least permanent deformation. The Honda Big red and John Deere Gator showed the greatest permanent deformation in lateral loading.

4.4 Vehicle and occupant rollover

Photographic snapshots of the vehicle and occupant rollover tests are contained in Appendix D.

The quad bike and occupant were subjected to ten rollover tests in nine configurations; roll, rearward pitch and forward pitch, with no CPD, a Quadbar CPD and lifeguard CPD. The injury response data from the MATD occupant indicated no serious risk of injury in any of the ten tests. It should be noted however that on the first forward pitch test the MATD neck was broken in half without a corresponding injury recorded. This component was replaced with a standard Hybrid III 50th percentile male ATD neck to conduct the three forward pitch tests. As such the data from the head and neck of the forward pitch tests can not be accurately compared to the data from the roll tests or rearward pitch. Similarly the calculated injury response and risk of injury for the forward pitch tests will not be accurate as the standard Hybrid III neck has different physical properties than the MATD neck.

In the five research and development tests, there was also a relatively low risk of life threatening injury from the nominal MATD instrument response data. The dummy however exhibited significant physical damage during the tests. In the first lateral roll test the MATD neck was broken. This neck was replaced with a standard Hybrid III 50th%ile male ATD neck for the remaining four development tests. In the second test the right shoulder clavicle was broken, resulting in the right arm detaching from the dummy. In two research and development tests one of the Varus valgus frangible knee pins were broken. The associated knee injury determined by the pin fracture accounted for the highest level of injury recorded in all of the vehicle and occupant rollover tests.

In all three lateral roll tests the first point of contact with the ground was the MATD head.
Without a CPD fitted the quad bike rolled onto the dummy and came to rest on the ATD with the dummy located between the quad bike and the ground.
With a Quadbar CPD fitted the quad bike did not fully roll onto the dummy.
With a lifeguard CPD fitted the quad bike rolled on the ATD and came to rest above the dummy with the rear supported by the lifeguard. The front of the quad bike was resting on the load rack and minimal mass was applied to the ATD.

In the rear pitch test conducted without a CPD fitted, the quad bike pitched rearward onto the ATD. The vehicle then continued to pitch up, pivoting about the front load rack, lifting the rear of the vehicle into the air. The rear of the vehicle then landed on the ATD a second time, coming to rest with the ATD leg located between the vehicle and the ground.
During the rear pitch test with the Quadbar CPD fitted, the CPD restricted the vehicle from pitching over. The vehicle came to rest on its rear edge with the dummy lying on top of the CPD. The top section of the Quadbar exhibited bending after the test.

In the rear pitch test with the Lifeguard CPD fitted, the CPD was the first item to contact the ground. The CPD then deformed, allowing the vehicle to pitch rearward over the dummy. The vehicle then rolled laterally to rest on its wheels, separated from the ATD.

In all three forward pitch tests the first point of contact with the ground was the MATD head. During the first forward pitch test conducted the MATD neck broke, separating into two parts. A standard Hybrid III 50th%ile neck was fitted. The forward pitch test with Lifeguard CPD was repeated such that all three forward pitch tests were conducted with the standard neck.
Without a CPD fitted the quad bike pitched onto the dummy and came to rest on the ATD with the dummy located between the quad bike and the ground.
With the Quadbar CPD fitted the quad bike pitched forward until the CPD contacted the ground. The vehicle came to rest above the dummy with the rear of the vehicle supported by the Quadbar, the front resting on the load rack and minimal mass applied to the ATD.
With the lifeguard CPD fitted the quad bike pitched forward onto the dummy. The vehicle then rolled laterally coming to rest on side next to the ATD. A crack at the base of the Lifeguard structure was evident after the test.

Two SSVs were tested in lateral roll with the MATD located in the driver seat on the 'low-side' of the tilt table. Each vehicle had previously been subjected to Roll-Over Protective Structure loading, and as such each vehicle ROPS had minor deformation prior to rollover testing.

When tested in roll the Tomcar TM2 ROPS made initial contact with the ground and resisted the vehicle from rolling over. The ROPS did not fail or collapse and exhibited approximately 35mm of permanent lateral deformation after the test. The MATD torso was well contained in however the head impacted the ground surface after the ROPS made contact and arrested the vehicle roll.

When roll tested the Yamaha Rhino vehicle ROPS made initial contact with the ground and resisted the vehicle from rolling over. The ROPS did not fail or collapse and showed minimal deformation after the test. The MATD head and shoulder contacted the ground surface.

5 Conclusions

The ground contact loads for one quad bike were measured with and without Crush Protection Devices fitted. The vehicle was positioned on its wheels, on its side and inverted.

When upright on its wheels the ground contact loads for each of the four wheels were similar.

When located on its side, the vehicle made contact with the ground on the sides of two wheels and at the plastic wheel guards. The mass distribution front to rear was similar.

When inverted, the vehicle made contact with the ground at the handlebars or headlight shroud at the front of the vehicle, and at the CPD or load rack at the rear of the vehicle. Typically the load applied at the front of the vehicle accounted for more than 75% of the total load.

An Anthropomorphic Test Device was fastened in five Side-by-side vehicles and rolled laterally to 45° to determine the level of occupant retention. The ATD was restrained in all vehicles and whilst the ATD did move laterally beyond the vehicle width in some vehicles, the occupant retention requirements of ANSI/ROHVA 1-2011were met for all vehicles.

The Roll-Over Protective Structure integrity of five Side-by-side vehicles was tested by applying a lateral load, vertical load and longitudinal load. The Honda Big red ROPS did not meet the vertical load requirements of ANSI/ROHVA 1-2011, experiencing significant yielding and deformation.

The John Deere Gator, Yamaha Rhino and Kubota RTV500 roll-over protective structures all met the load and energy requirements of ANSI/ROHVA 1-2011 without failure.

The Tomcar TM2 ROPS met the load requirements of ANSI/ROHVA 1-2011. Due to the stiff Tomcar TM2 ROPS construction exhibiting relatively minor deformation in the lateral load condition it did not meet the energy requirement, but exceeded the load requirement by more than double.

One quad bike and Motorcycle Anthropomorphic Test Device were subjected to lateral roll, rearward pitch-over and forward pitch-over tests to determine the likelihood of occupant injury. The vehicle was tested in each roll direction without a Crush Protection Device fitted, with a Quadbar CPD fitted and with a Lifeguard CPD fitted.

In all tests the data recorded by the MATD showed a minor chance of injury however this is not consistent with the significant physical damage that occurred to the MATD without a corresponding injury recorded.

Fitment of a CPD typically had little effect on the dummy impact with the ground in the lateral roll and forward pitch tests. In rearward pitch tests the CPDs impacted the ground before the dummy, but had little effect on the dummy interaction with the ground.

Typically without a CPD fitted the vehicle came to rest on the ATD, imparting a load. Typically with a CPD fitted, the vehicle came to rest separated from the ATD, or supported the mass of the vehicle above the ATD.

Two Side by Side Vehicles were fitted with a Motorcycle Anthropomorphic Test Device and subjected to a lateral roll to determine the likelihood of occupant injury. The data recorded by the MATD showed a minor chance of injury. In both tests the roll-over protective structure stopped the vehicle from experiencing inverted rollover, and supported the partially inverted vehicle above the occupant without failure. For both vehicles the MATD exhibited head excursion from the vehicle which impacted the ground surface.

6 Reference Material

[1] Recreational Off-Highway Vehicle Association 2011, *American National Standard for Recreational Off-Highway Vehicles,* ANSI/ROHVA 1 - 2011, Recreational Off-Highway Vehicle Association, California United States of America.

[2] ISO 2005, *Motorcycles – Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles* , ISO 13232:2005, ISO (International Organization for Standardization), Geneva Switzerland.

7 Disclaimer

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8 Appendices

Appendix A – Test matrix
Appendix B – Instrument response data
Appendix C – Test specimen details
Appendix D – Test photographs
Appendix E – Instrument details

Appendix A
Test matrix

Appendix Prepared by: Drew Sherry

Appendix Checked by: Ross Dal Nevo

1. Test number matrix

	Vehicle make	Honda			Honda	Kubota	John Deere	Yamaha	Tomcar
	Vehicle model	TRX500			Bigred	RTV500	Gator XUV825i	Rhino 700	TM2
	Specimen number	TS59641			TS57210	TS57208	TS57209	TS57207	TS59881
Test	Test setup / CPD	Nil	Quadbar	Lifeguard					
SSV Occupant retention	Tilt towards driver side, hands on steering wheel	---	---	---	G140054 G140055	G140059	G140062	G140065	G140068
	Tilt toward passenger side, hands on vehicle hand holds	---	---	---	G140053	G140056 G140057	G140060	G140063	G140066
	Tilt towards passenger side, hands on lap	---	---	---	---	G140058	G140061	G140064	G140067
Roll Over Protective Structure	Lateral pull	---	---	---	G140096	G140094	G140089 G140093	G140092	G140095
	Vertical pull	---	---	---	G140097	G140100	G140090 G140104	G140099	G140098
	Longitudinal pull	---	---	---	---	G140101	G140091 G140106	G140102	G140103
Vehicle and occupant rollover	Lateral roll	G140075	G140077	G140076	---	---	---	G140108	G140107
	Rearward pitch	G140080	G140078	G140079	---	---	---	---	---
	Forward pitch	G140088	G140085	G140082 G140087	---	---	---	---	---

--- Not tested in this configuration

Appendix B
Instrument Response Data

Intentionally not added to this report as file is large (404 pages)

Appendix C
Test specimen details

Appendix Prepared by: Drew Sherry

Appendix Checked by: Ross Dal Nevo

1. Vehicle details and specimen numbers

Vehicle make	Honda	Yamaha	Kubota	John Deere	Honda	Tomcar
Vehicle model	Foreman TRX500	Rhino YXR 700	RTV500	Gator XUV825i	Big Red MUV700	TM-2
Test specimen number	TS59641	TS57207	TS57208	TS57209	TS57210	TS58248
Vehicle type	Quad bike agricultural	SSV	SSV	SSV	SSV	SSV
Engine capacity (cc)	475.3	686	456	812	675	1000
Driven wheels	4WD (switchable)	4WD (switchable)	4WD (switchable)	4WD (switchable)	4WD (switchable)	rear
Seat type	saddle	bucket	bench	bucket	bucket	bucket
Driver location	centre	left	left	left	left	right
Tyres front	Maxxis M975	Maxxis	OTR 350 Mag off road	CST ANCLA	Maxxis bighorn	Deestone
Tyres rear	Maxxis M978	Maxxis	OTR 350 Mag off road	CST ANCLA	Maxxis bighorn	Deestone swampwitch
Tyre size front	AT25x8-12	25x8-12	24x9-12	26x9-12	25x10-12	AT25x8-12
Tyre size rear	AT25x10-12	25x10-12	24x11-12	26x11-12	25x10-12	26x12-12
Manufacturer recommended tyre pressure front (kPa)	30	70	100	97	70	105
Manufacturer recommended tyre pressure rear (kPa)	30	98	100	97 to 124	120	140
Fuel tank capacity (l)	15	30	20	20	30	26
Seating capacity	1	2	2	2	2	2
Vehicle width (mm)	1205	1385	1390	1500	1626	1780
Vehicle track width - front (mm)	930	1130	1016	1280	1290	1520
Vehicle track width - rear (mm)	925	1096	1041	1304	1296	1460
Vehicle length (mm)	2127	2885	2690	2870	2913	2820
Vehicle wheelbase (mm)	1281	1910	1800	2010	1922	2050
Front cargo capacity (kg)	30	0	0	0	0	0
Rear cargo capacity (kg)	60	181	200	454	454	200
Maximum vehicle payload capacity (kg)	220	367	430	635	767	400
Unladen kerb mass (kg)	293	553	621	776	647	766
Maximum laden vehicle mass (kg)	513	920	1051	1411	1414	1166
Distance of unladen COG behind front axle (mm)	608	1062	1081	1176	973	1333
Distance of unladen COG from vehicle centreline (mm)	8 right	33 right	7 left	6 right	22 right	0

2. Crush Protection Device (CPD) details

CPD device	Quadbar	Lifeguard
Manufacturer	QB Industries	Ag TECH industries
CPD reference number	CPD1	CPD2
Mass	8.5kg	14.8kg
Mounting location	Behind rear load rack & tow hitch	Rear load rack
Mounting method	Two U-bolts to rear load rack & tow ball bolt	Four J-bolts to rear load rack


Quadbar

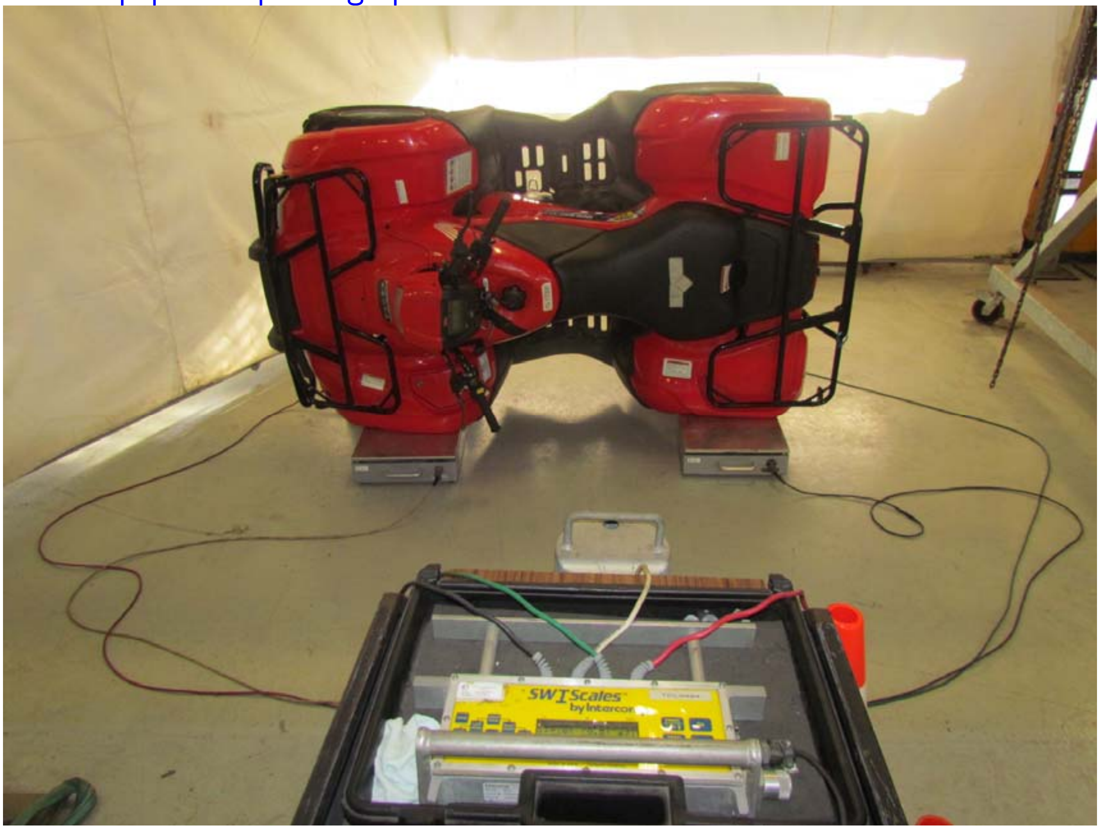

Lifeguard

Appendix D
Test Photographs

Appendix Prepared by: Drew Sherry

Appendix Checked by: Ross Dal Nevo

1. Test equipment photographs



Ground contact load, single axis (vertical) vehicle load scales with digital display


Tilt table (lowered, horizontal position)

Tilt table (partially raised position)

Tilt table top surface with expanded mesh anti-slip plates located under vehicle tyres

Roll-Over Protective Structure rigid steel test fixture, rails and adjustable vehicle mounting stands (lateral and longitudinal tests)

Roll Over Protective Structure vertical test steel frame (under vehicle) and load plate (on top of ROPS)

2. Vehicle photographs

Honda Foreman TRX500 (TS57200)

Honda Foreman TRX500 (TS57200)

Yamaha Rhino YXR700 (TS57207)

Yamaha Rhino YXR700 (TS57207)

Kubota RTV500 (TS57208)

Kubota RTV500 (TS57208)

John Deere Gator XUV825i (TS57209)

John Deere Gator XUV825i (TS57209)

Honda Big Red MUV700 (TS57210)

Honda Big Red MUV700 (TS57210)

Tomcar TM-2 (Typical)

Tomcar TM-2 (Typical)

3. Crush Protection Device (CPD) photographs

QB Industries Quadbar

Typical Quadbar installation

Ag-TECH Industries Lifeguard

Typical Lifeguard installation

4. Test photographs – Ground contact load

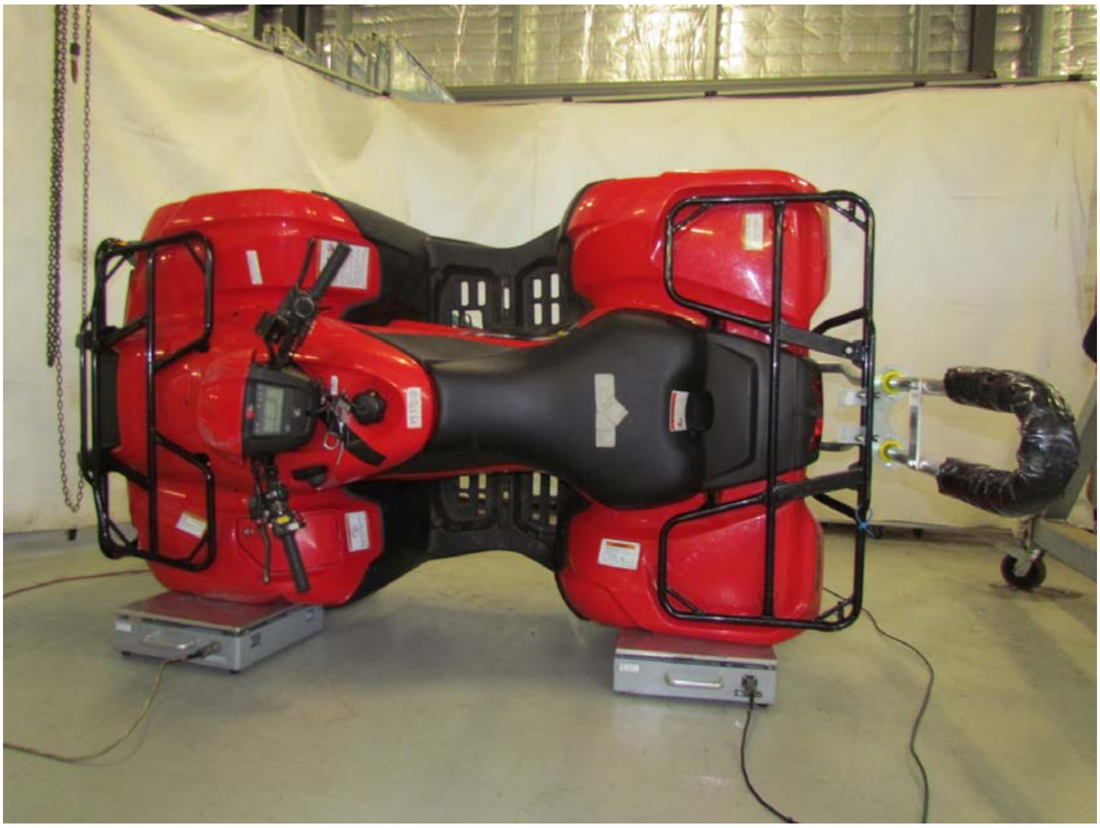
Honda TRX500 – No CPD, Upright

Honda TRX500 – No CPD, Left side

Honda TRX500 – No CPD, Left side

Honda TRX500 – No CPD, Inverted

Honda TRX500 – Quadbar, Upright

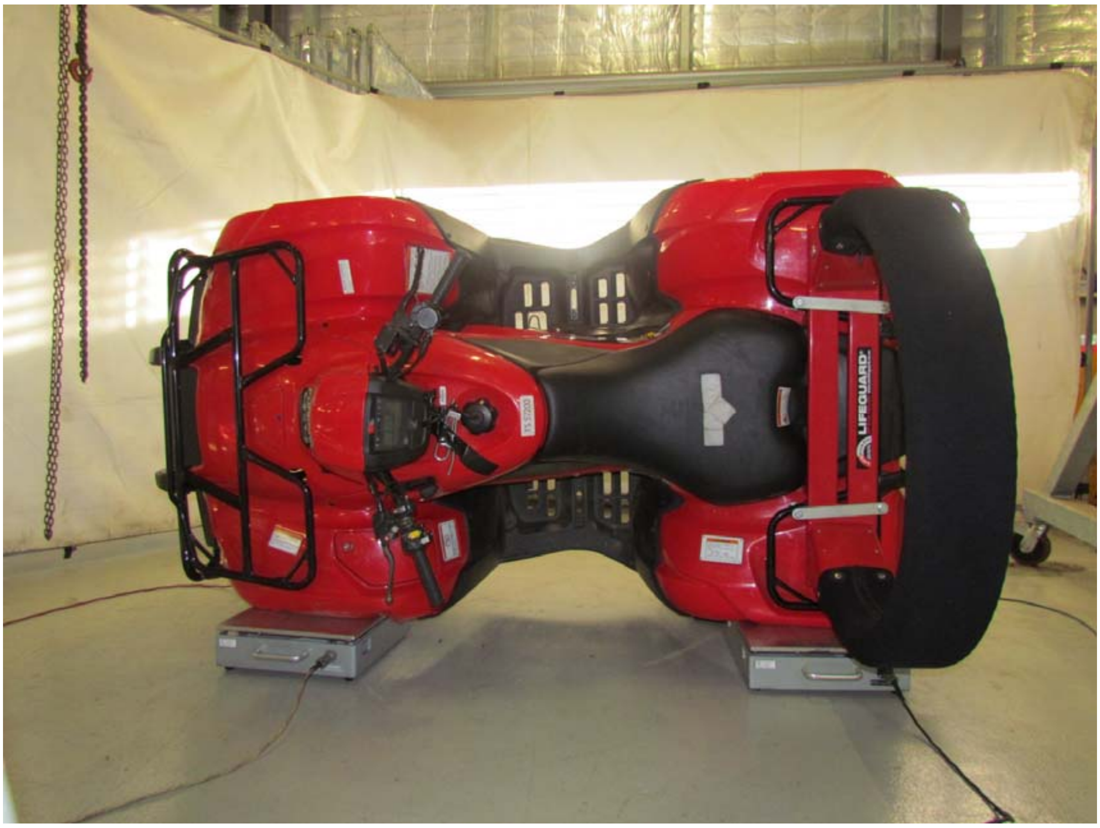


Honda TRX500 – Quadbar, Left side

Honda TRX500 – Quadbar, Inverted

Honda TRX500 – Quadbar, Inverted & rolled partially to left

Honda TRX500 –Lifeguard, Upright



Honda TRX500 –Lifeguard, Left side

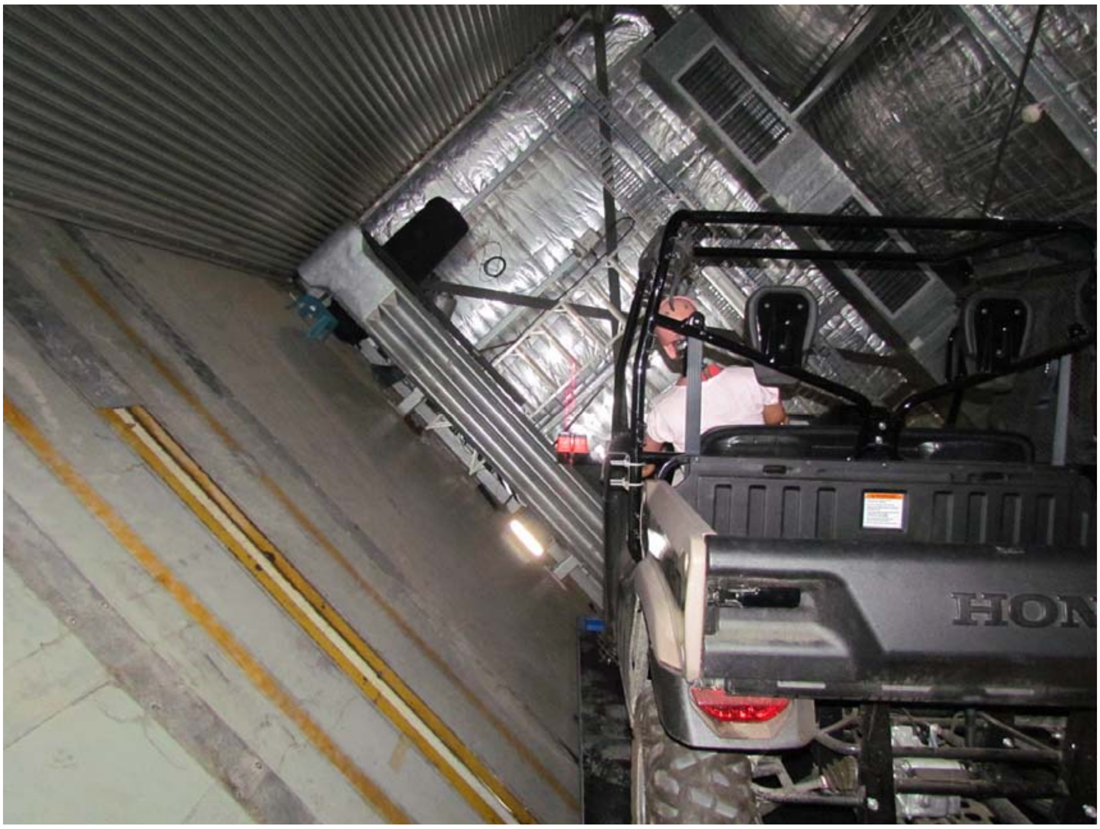
Honda TRX500 –Lifeguard, Inverted

Honda TRX500 – Lifeguard, Inverted & rolled partially to left

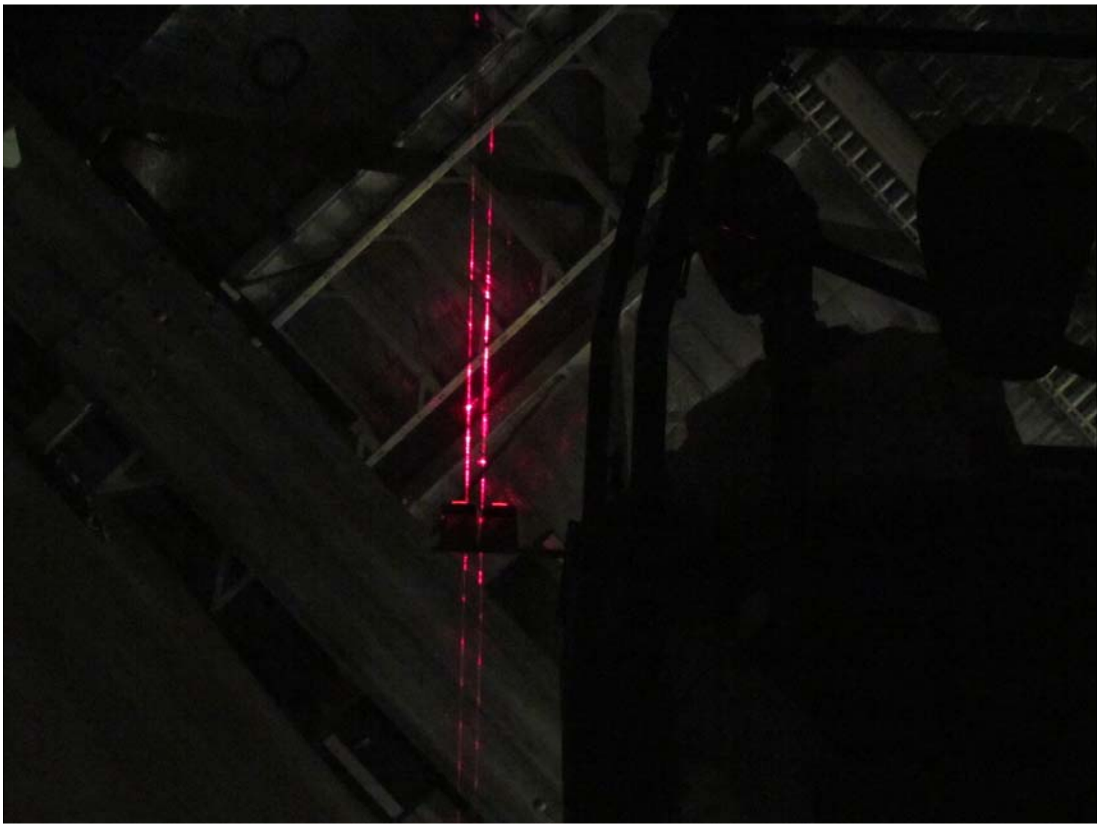
5. Test photographs – Side by Side Vehicle occupant retention

Side by Side Vehicle occupant retention – typical vehicle setup on tilt table

Side by Side Vehicle occupant retention – typical vehicle at 45° tilt angle



Side by Side Vehicle occupant retention – typical vehicle at 45° tilt angle with longitudinal/vertical planes projected along side vehicle located 127mm and 178mm from widest point of vehicle

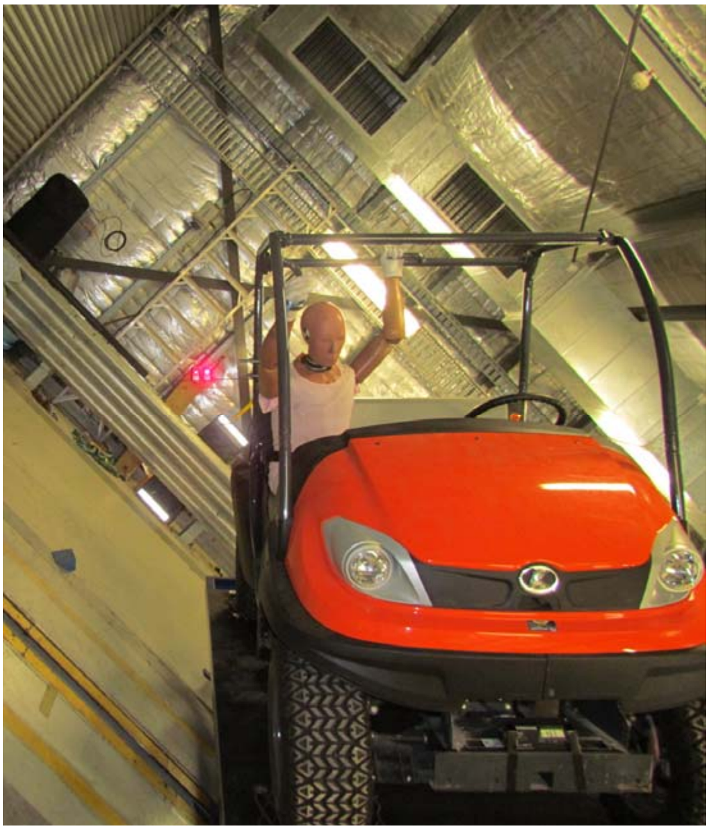


Side by Side Vehicle occupant retention – typical vehicle at 45° tilt angle with longitudinal/vertical planes projected along side vehicle located 127mm and 178mm from widest point of vehicle

Side by Side Vehicle occupant retention – Test G140053

Side by Side Vehicle occupant retention – Test G140054

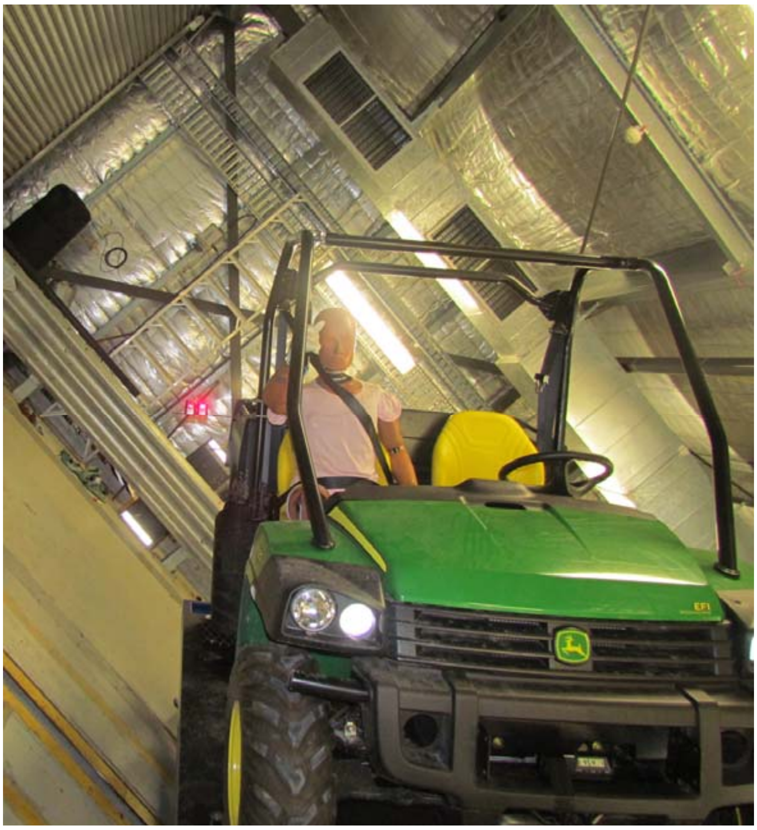
Side by Side Vehicle occupant retention – Test G140055


Side by Side Vehicle occupant retention – Test G140056

Side by Side Vehicle occupant retention – Test G140057

Side by Side Vehicle occupant retention – Test G140058

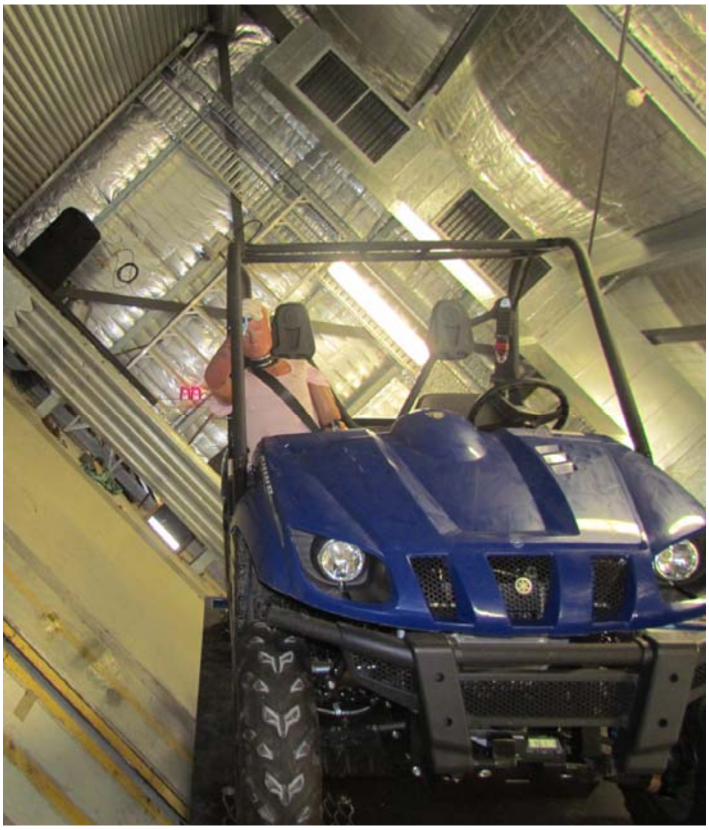
Side by Side Vehicle occupant retention – Test G140059



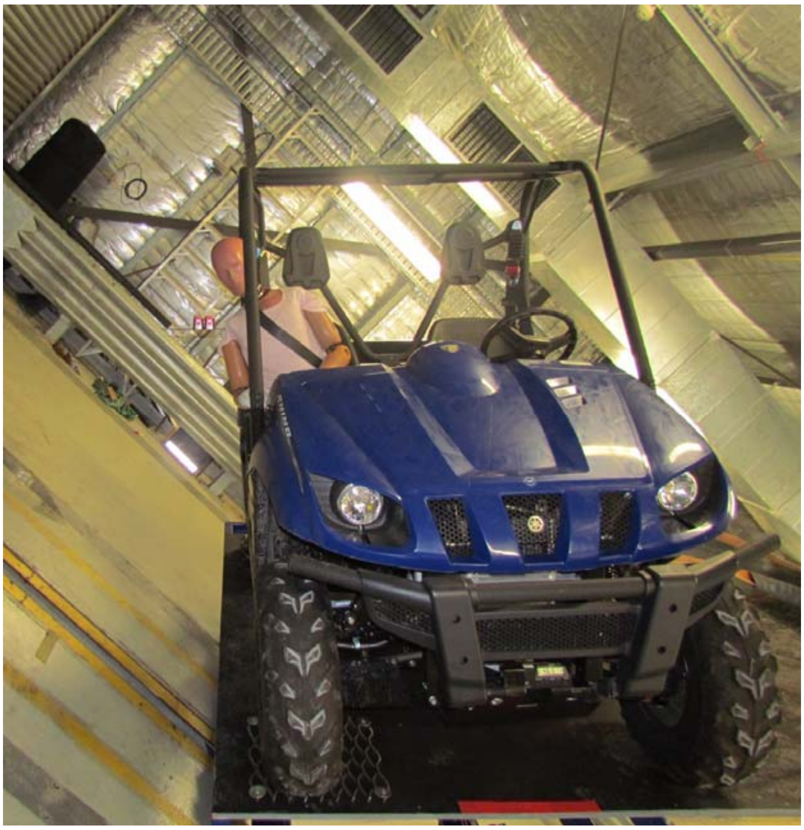
Side by Side Vehicle occupant retention – Test G140060


Side by Side Vehicle occupant retention – Test G140061


Side by Side Vehicle occupant retention – Test G140062



Side by Side Vehicle occupant retention – Test G140063



Side by Side Vehicle occupant retention – Test G140064

Side by Side Vehicle occupant retention – Test G140065

Side by Side Vehicle occupant retention – Test G140066

Side by Side Vehicle occupant retention – Test G140067

Side by Side Vehicle occupant retention – Test G140068

6. Test photographs – Side by Side Vehicle Roll-Over Protective Structure

ROPS test – Lateral pull typical setup. Vehicle secured to mounting stands.
Hydraulic cylinder, load cell & chain secured between Rigid test fixture and vehicle ROPS

ROPS test – Lateral pull typical setup, Load Distribution Device (LDD)

ROPS test – Vertical pull typical setup. Vehicle secured to steel frame under chassis.
Two hydraulic cylinders & load cells secured between Rigid top plate and steel frame under vehicle

ROPS test – Vertical pull typical setup. Rigid top plate aligned with ROPS centreline

ROPS test – Longitudinal pull typical setup. Vehicle secured to mounting stands.
Hydraulic cylinder, load cell & chain secured between Rigid test fixture and vehicle ROPS

ROPS test – Lateral pull typical setup,
Load Distribution Device (LDD) aligned with ROPS centreline

SSV ROPS test – Lateral test G140089

SSV ROPS test – Vertical test G140090

SSV ROPS test – Longitudinal test G140091


SSV ROPS test – Lateral test G140092

SSV ROPS test – Lateral test G140093

SSV ROPS test – Lateral test G140094

SSV ROPS test – Lateral test G140095

SSV ROPS test – Lateral test G140096

SSV ROPS test – Vertical test G140097

SSV ROPS test – Vertical test G140098

SSV ROPS test – Vertical test G140099

SSV ROPS test – Vertical test G140100

SSV ROPS test – Longitudinal test G140101

SSV ROPS test – Longitudinal test G140102

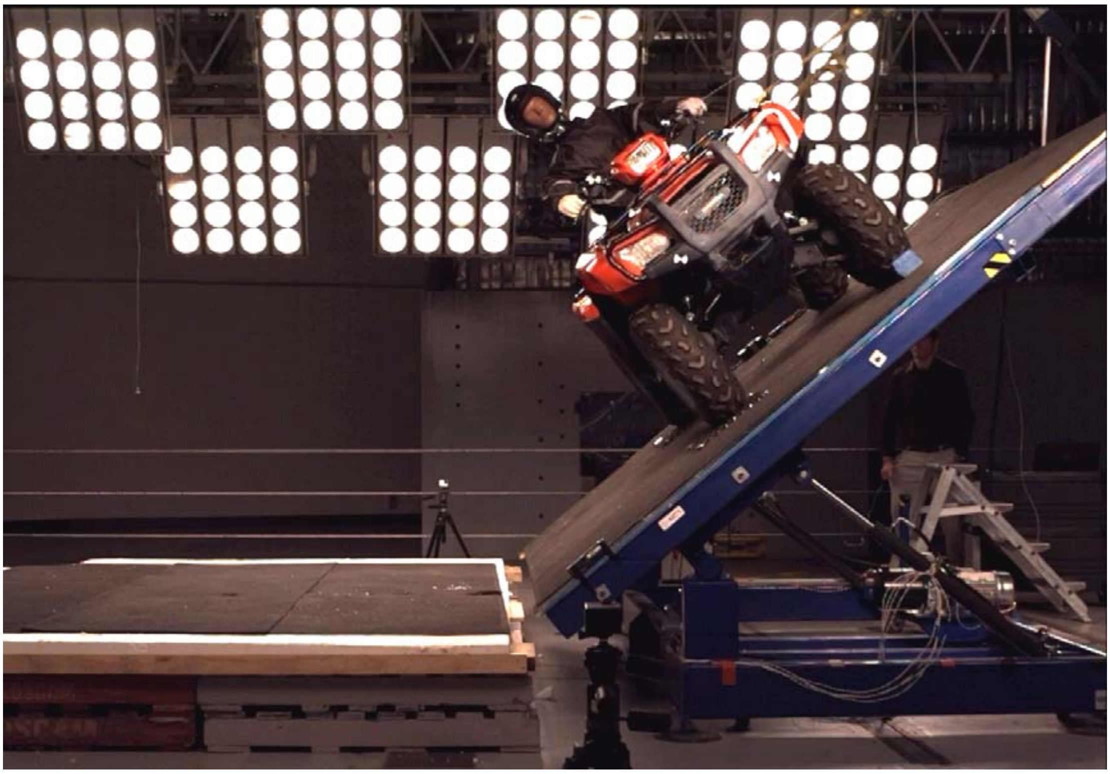
SSV ROPS test – Longitudinal test G140103

SSV ROPS test – Vertical test G140104

SSV ROPS test – Longitudinal test G140106

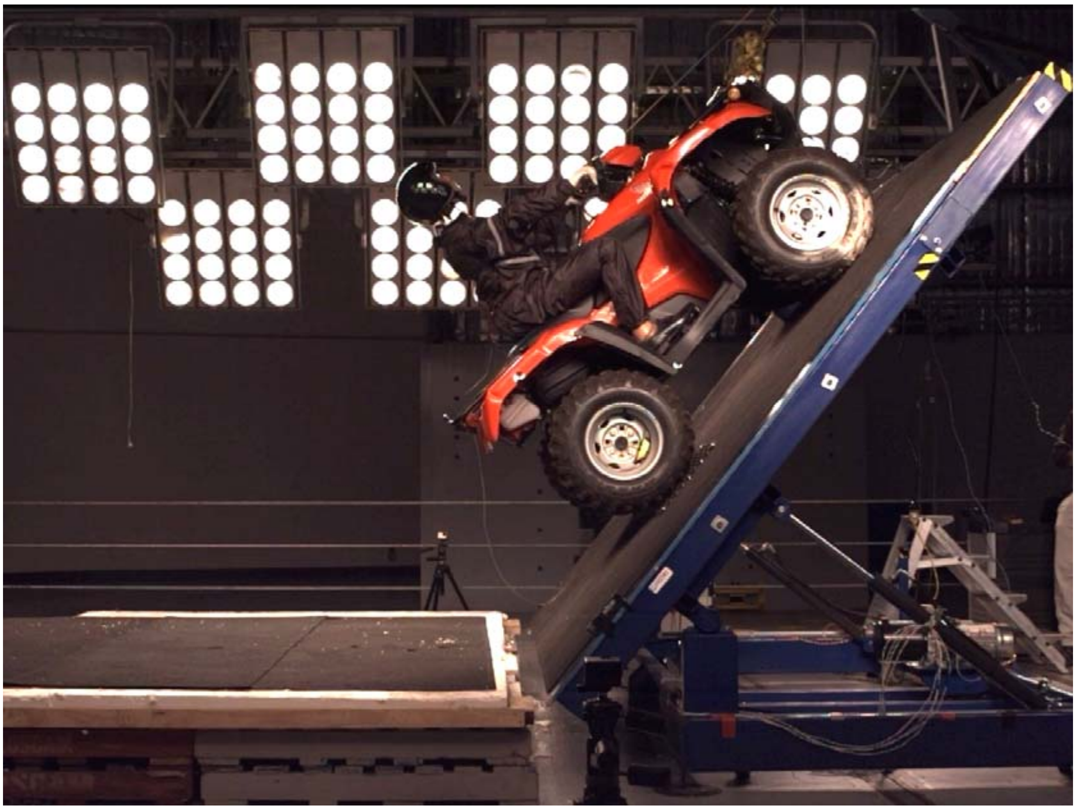
7. Test photographs – Vehicle and occupant rollover

Vehicle and occupant rollover – typical test setup, quadbike lateral roll



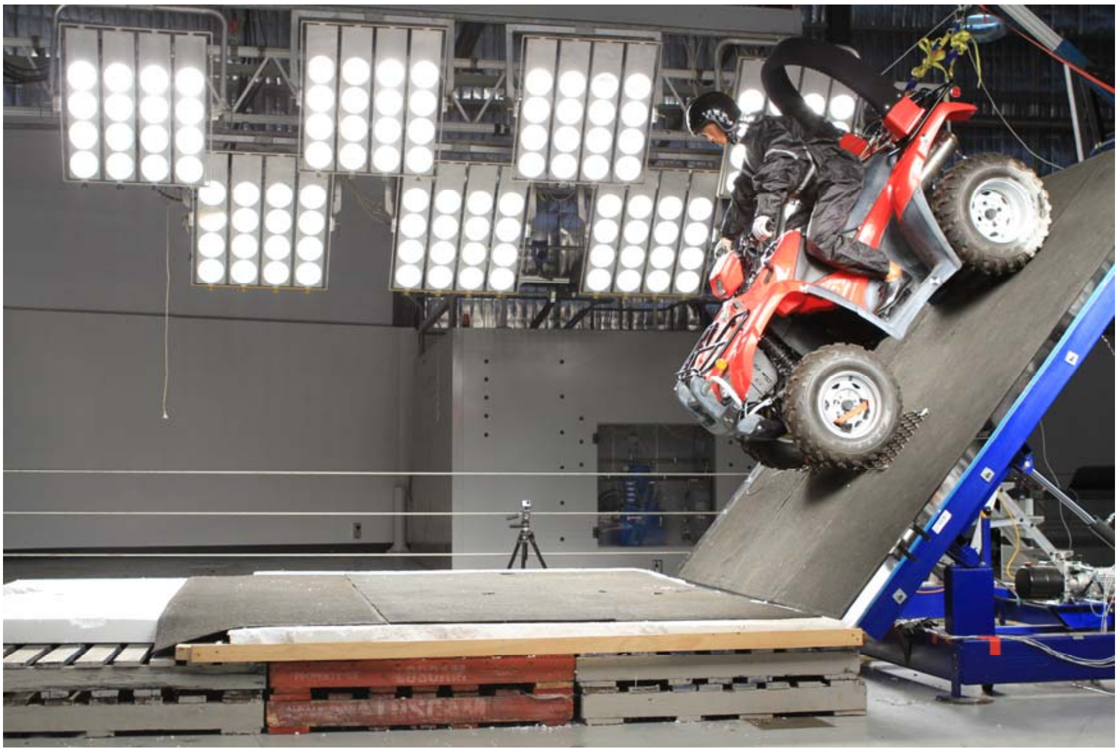
Vehicle and occupant rollover – typical test setup, quadbike lateral roll, immediately prior to vehicle and ATD release

Vehicle and occupant rollover – typical test setup, quadbike rearward pitch



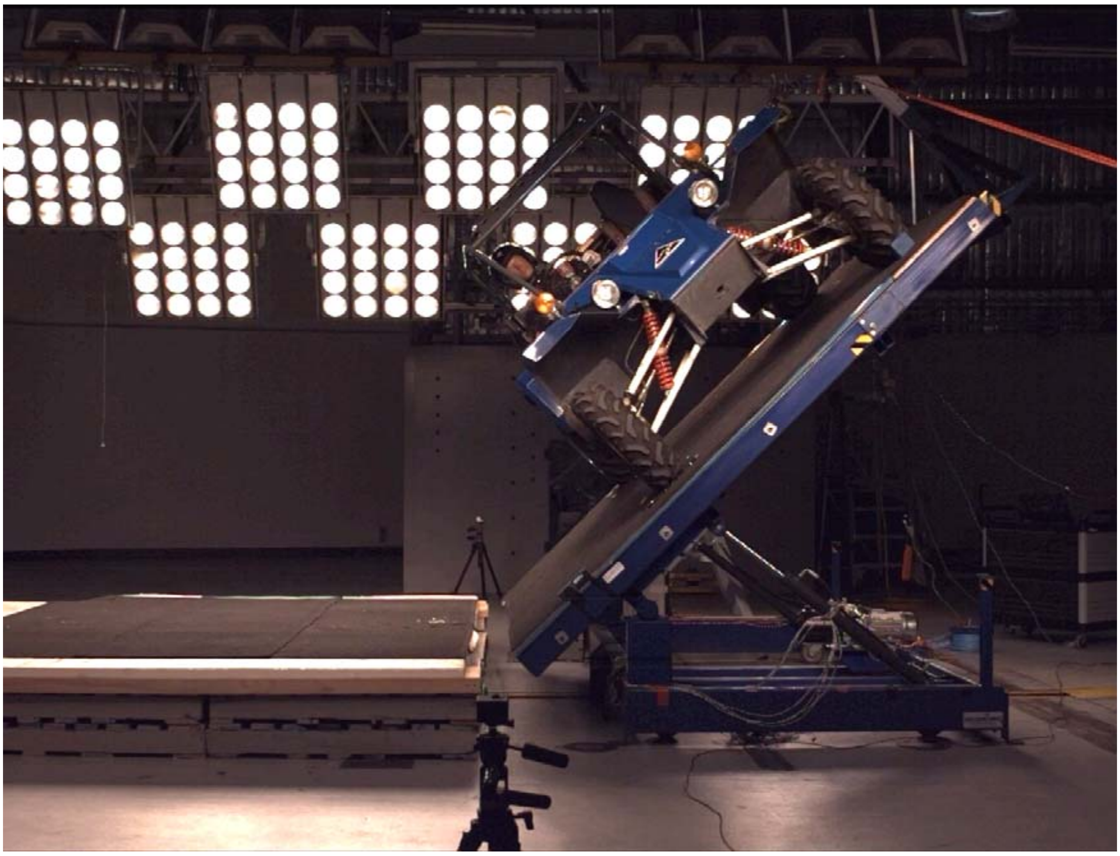
Vehicle and occupant rollover – typical test setup, quadbike rearward pitch, immediately prior to vehicle and ATD release

Vehicle and occupant rollover – typical test setup, quadbike forward pitch

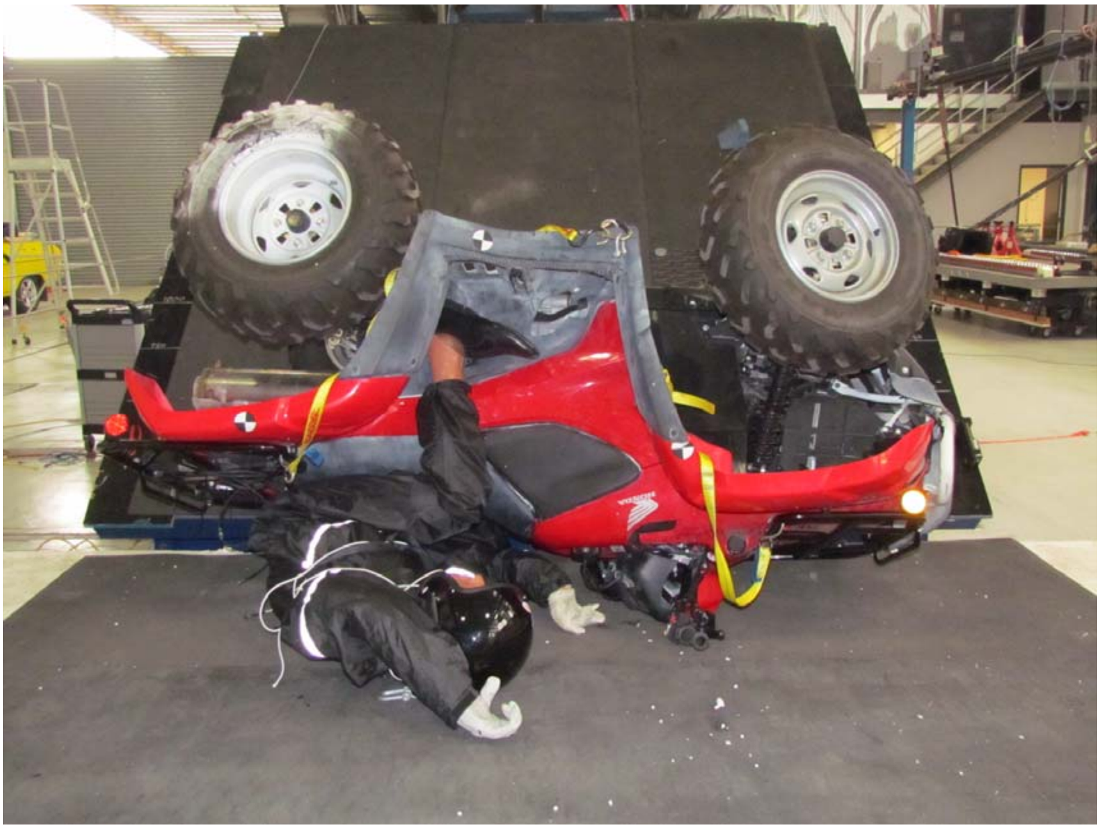


Vehicle and occupant rollover – typical test setup, quadbike forward pitch, immediately prior to vehicle and ATD release

Vehicle and occupant rollover – typical test setup, SSV lateral roll



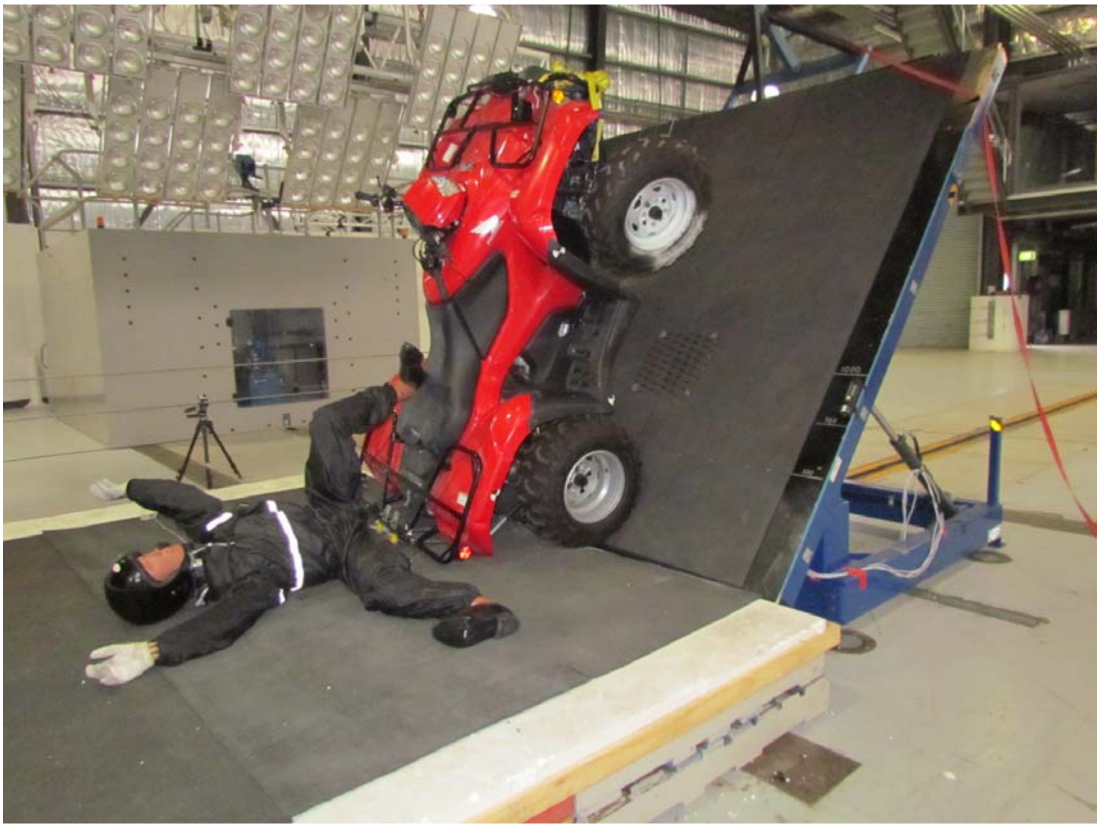
Vehicle and occupant rollover – typical test setup, SSV lateral roll, immediately prior to vehicle and ATD release



Vehicle and occupant rollover – Test G140075 lateral roll, No CPD, vehicle rest position

Vehicle and occupant rollover – Test G140076 lateral roll, Lifeguard CPD, vehicle rest position

Vehicle and occupant rollover – Test G140077 lateral roll, Quadbar CPD, vehicle rest position



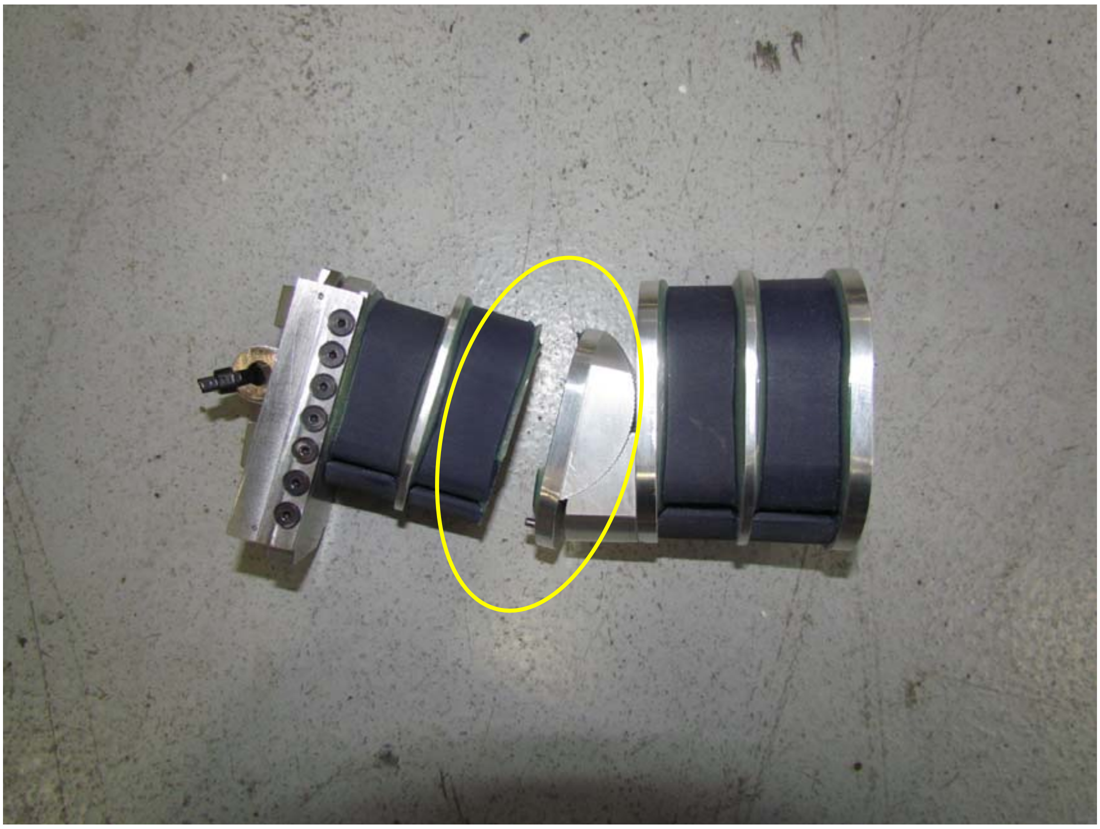
Vehicle and occupant rollover – Test G140078 rearward pitch, Quadbar CPD, vehicle rest position

Vehicle and occupant rollover – Test G140079 rearward pitch, Lifeguard CPD, vehicle rest position

Vehicle and occupant rollover – Test G140080 rearward pitch, No CPD, vehicle rest position

Vehicle and occupant rollover – Test G140082 forward pitch, Lifeguard CPD, vehicle rest position

Vehicle and occupant rollover – Test G140082, damage to MATD neck

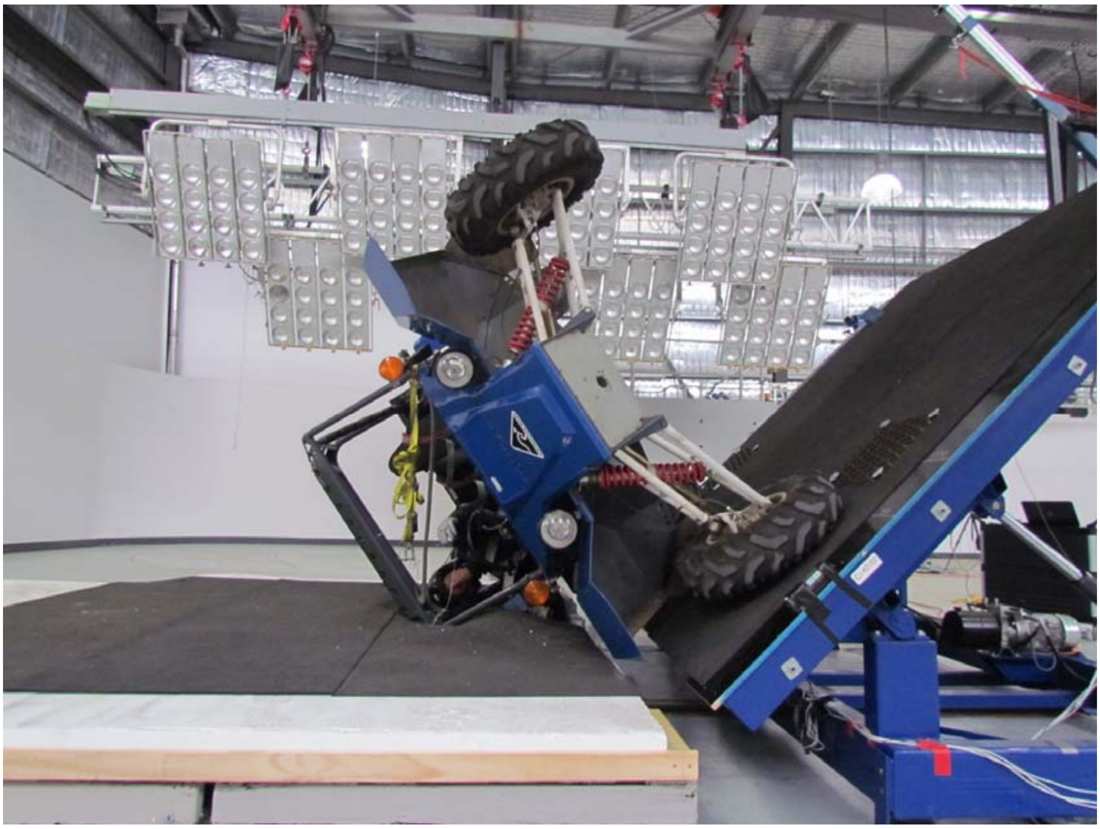


Vehicle and occupant rollover – Test G140082, damage to MATD neck

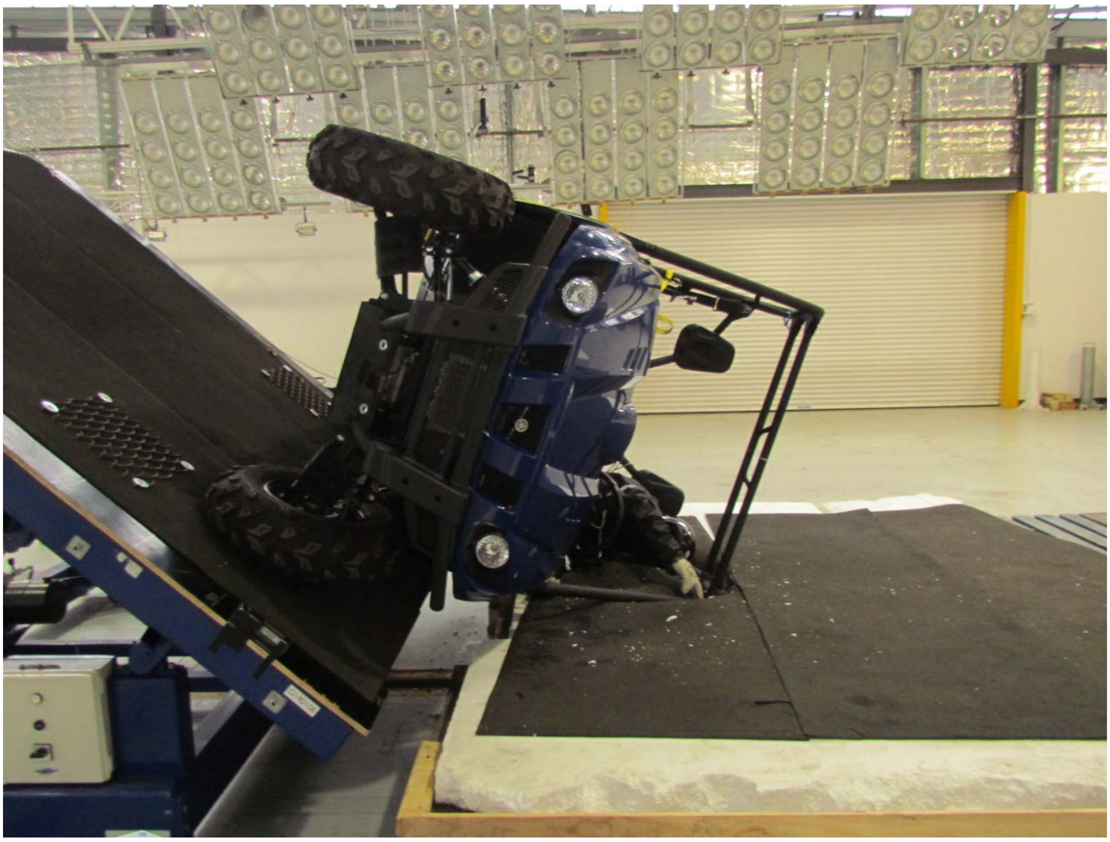
Vehicle and occupant rollover – Test G140085 forward pitch, Quadbar CPD, vehicle rest position

Vehicle and occupant rollover – Test G140087 forward pitch, Lifeguard CPD, vehicle rest position

Vehicle and occupant rollover – Test G140088 forward pitch, No CPD, vehicle rest position



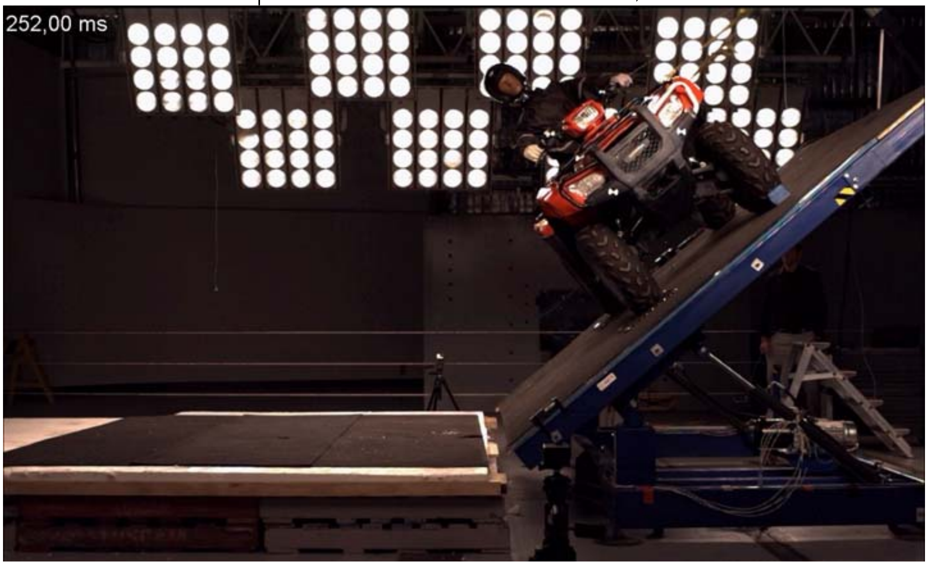
Vehicle and occupant rollover – Test G140107 lateral roll, vehicle rest position

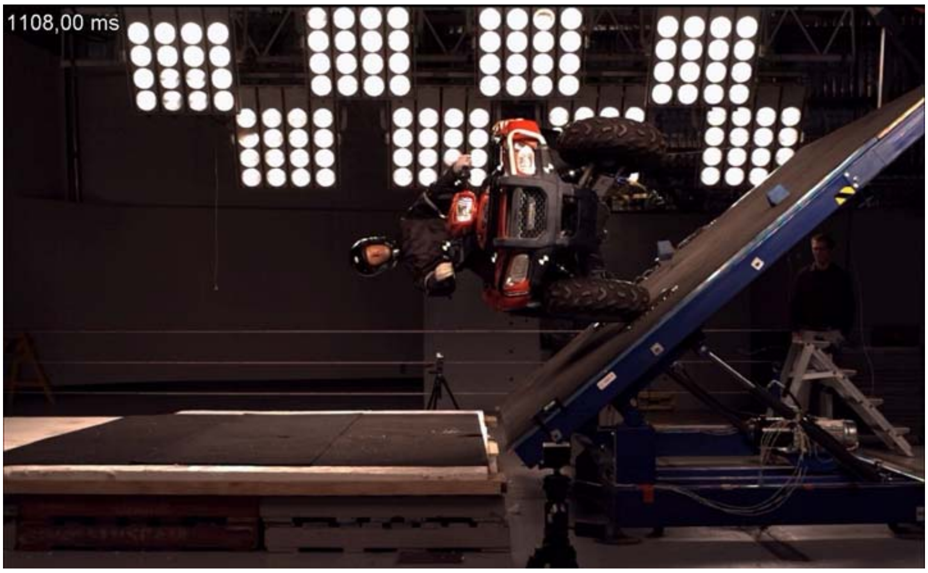


Vehicle and occupant rollover – Test G140108 lateral roll, vehicle rest position

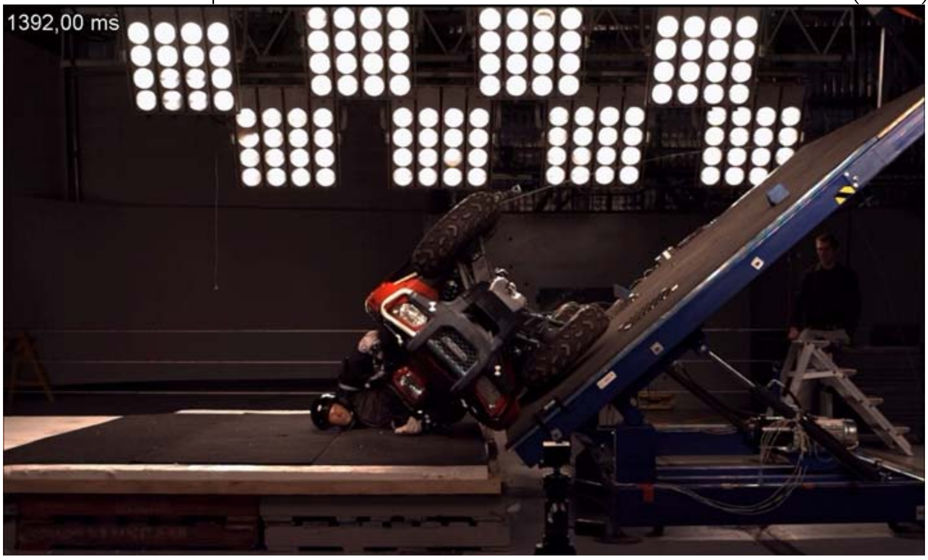
8. Test snapshots - Vehicle and occupant rollover

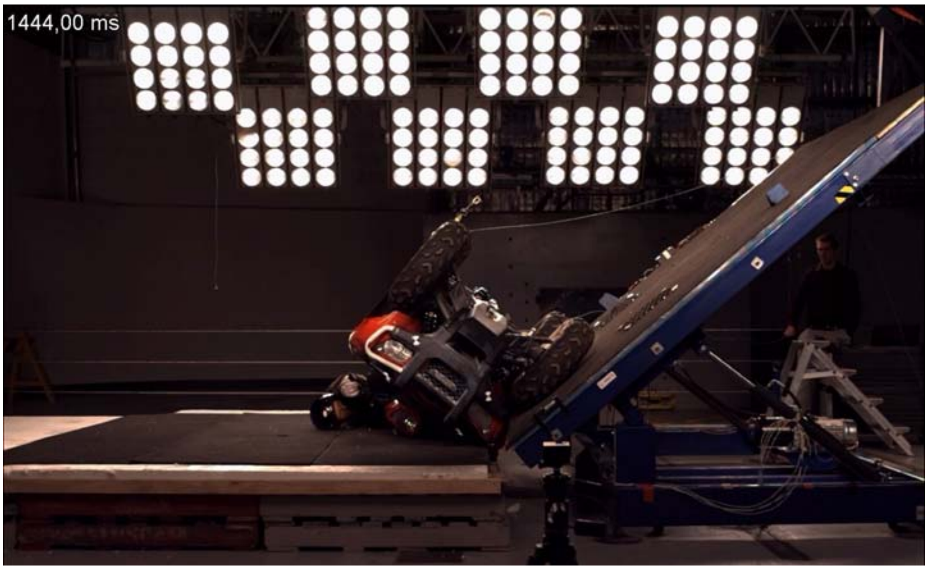
Vehicle and occupant rollover – Test G140075, lateral roll no CPD

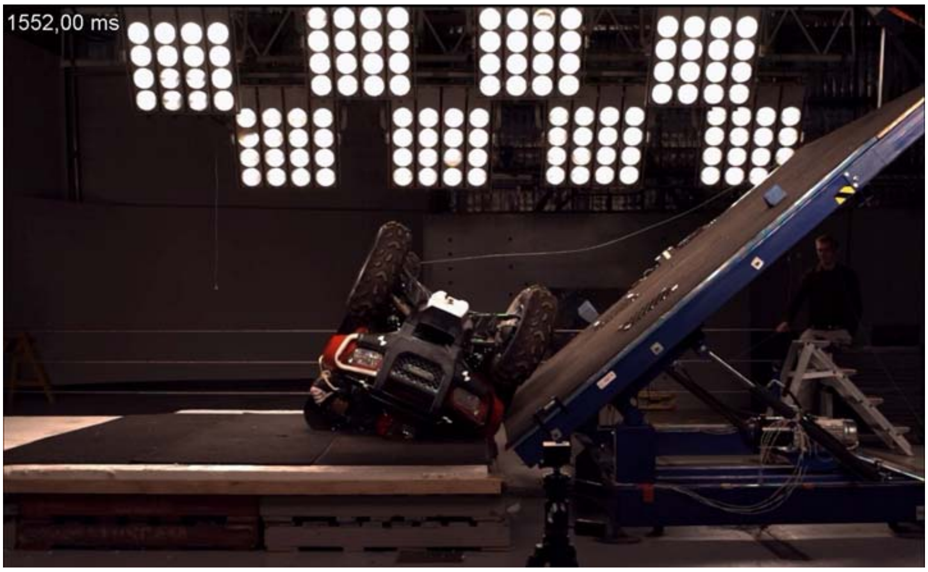




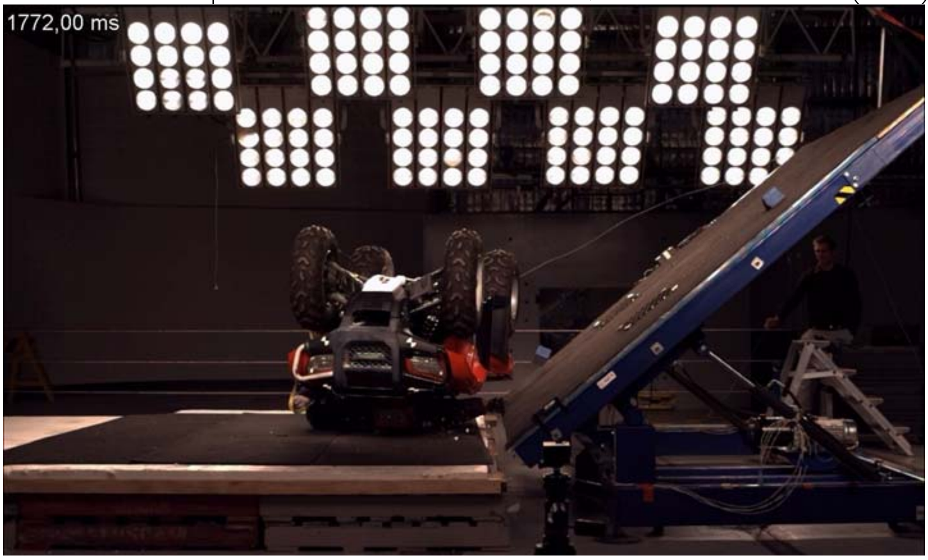
Vehicle and occupant rollover – Test G140075, lateral roll no CPD (cont.)

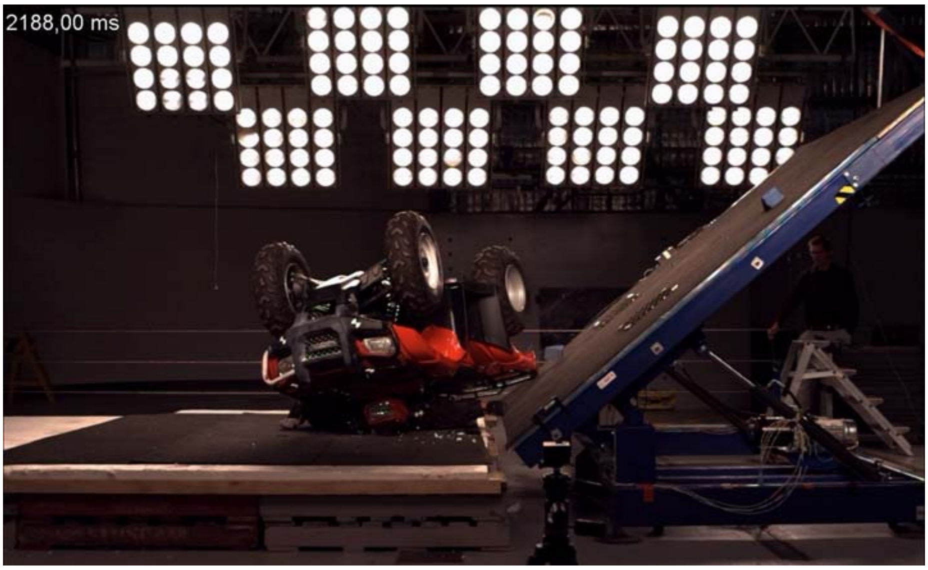


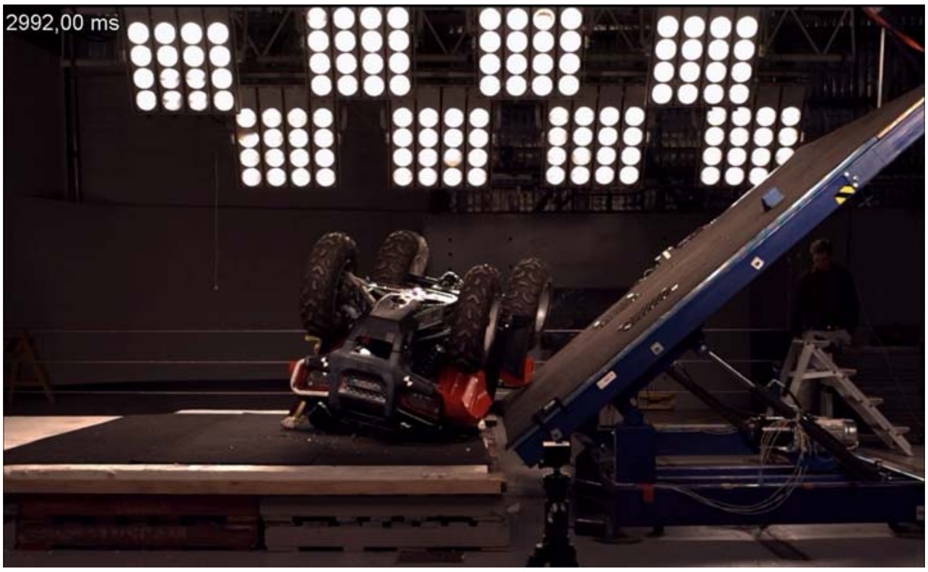




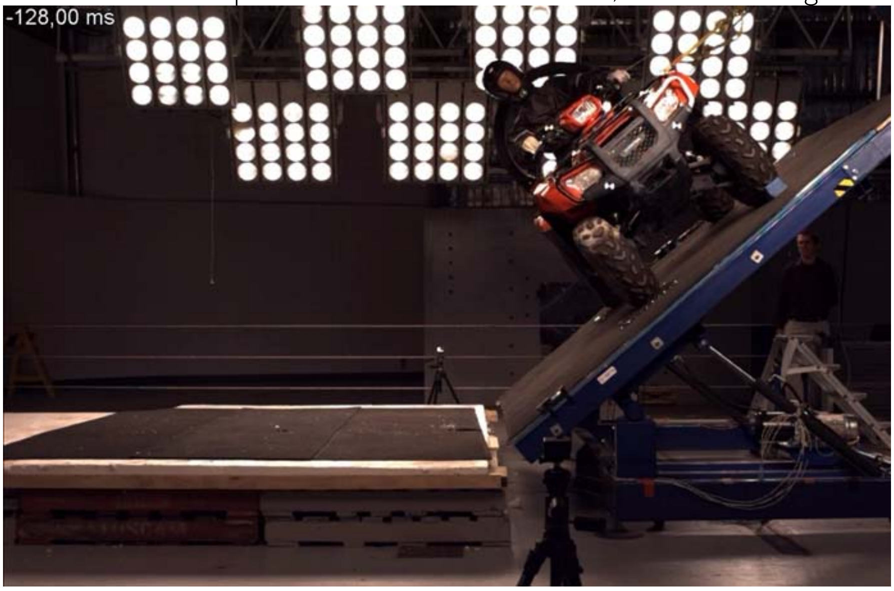
Vehicle and occupant rollover – Test G140075, lateral roll no CPD (cont.)

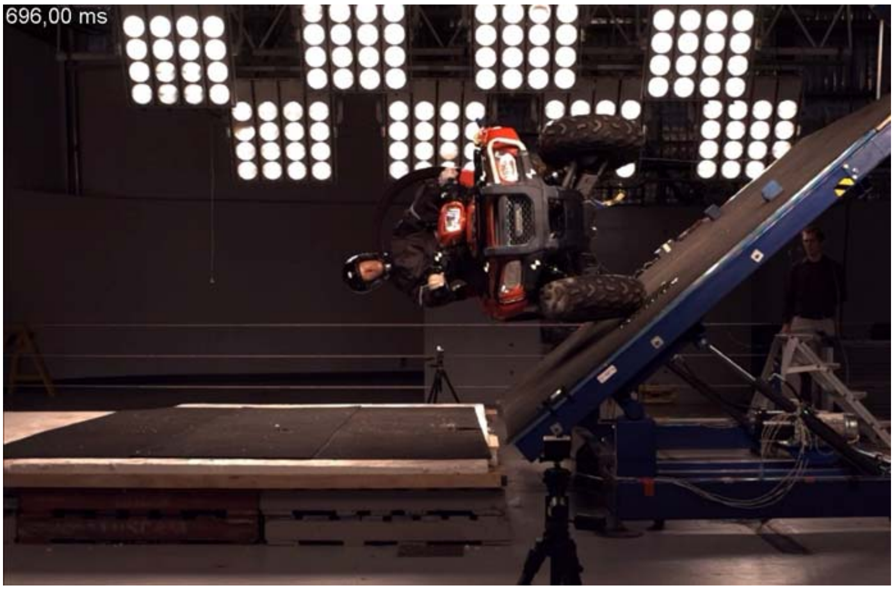




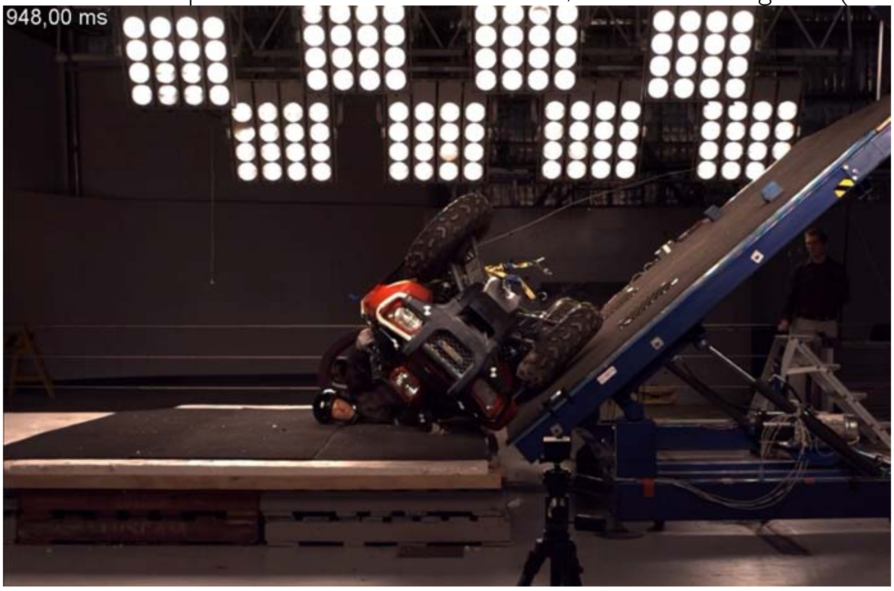


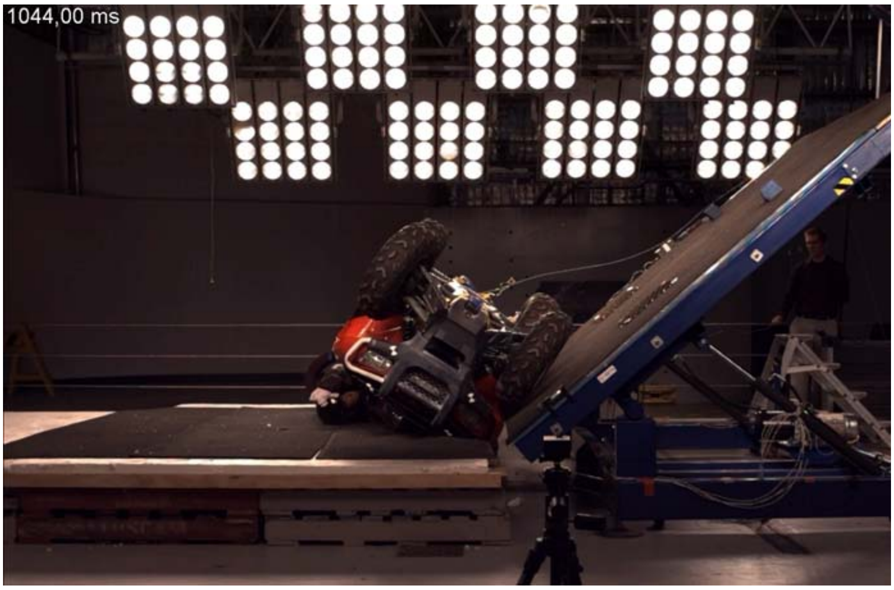
Vehicle and occupant rollover – Test G140076, lateral roll Lifeguard

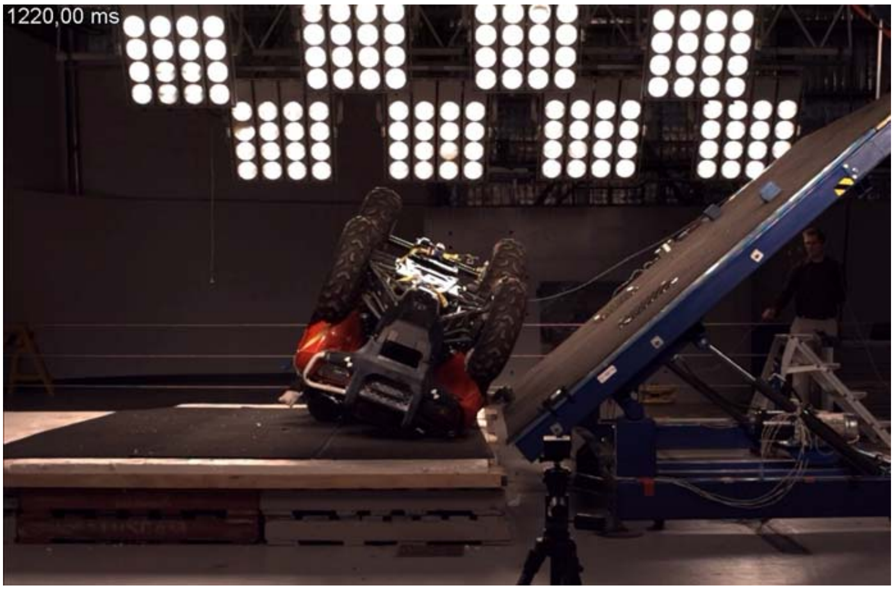




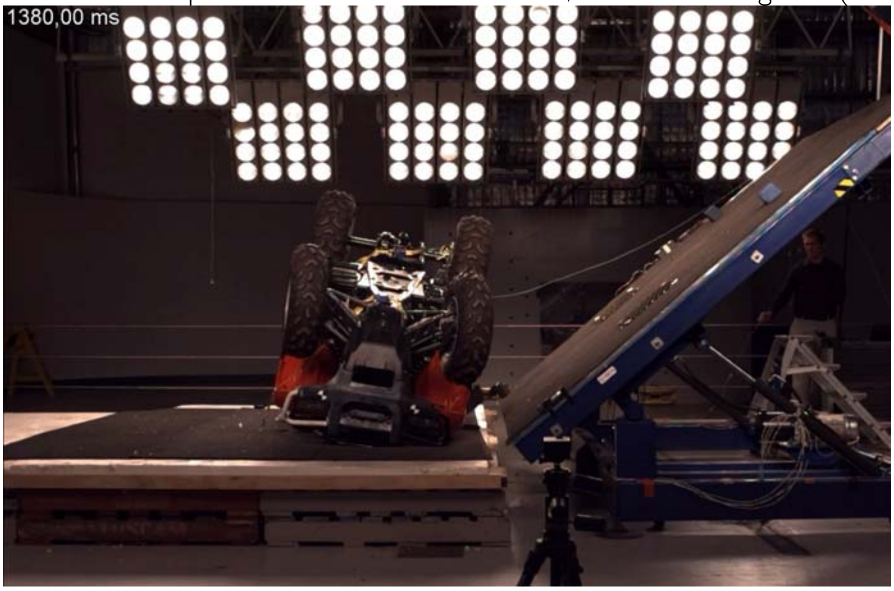
Vehicle and occupant rollover – Test G140076, lateral roll Lifeguard (cont.)

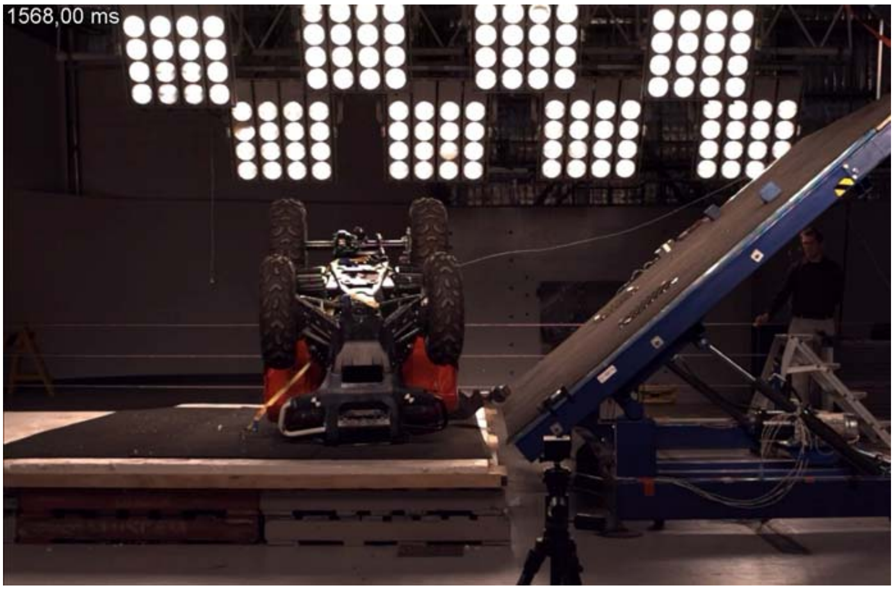




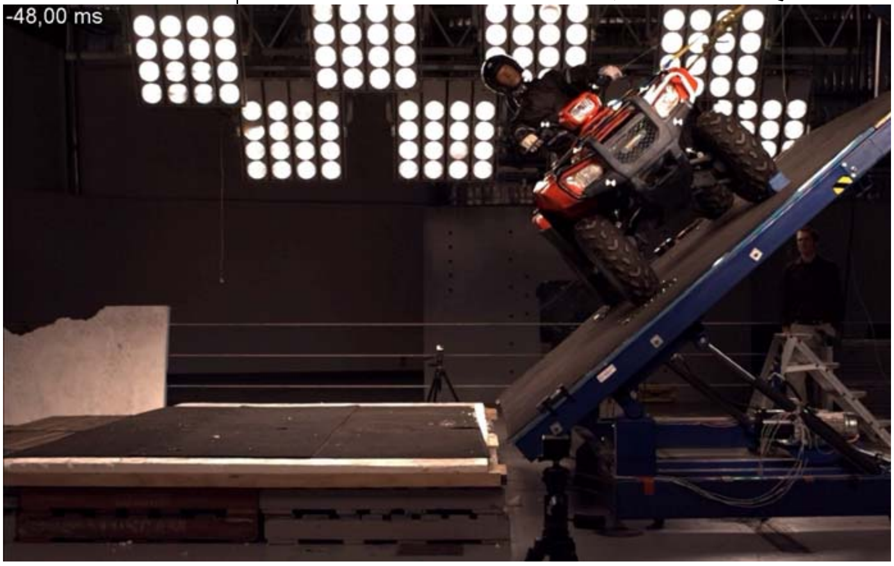


Vehicle and occupant rollover – Test G140076, lateral roll Lifeguard (cont.)

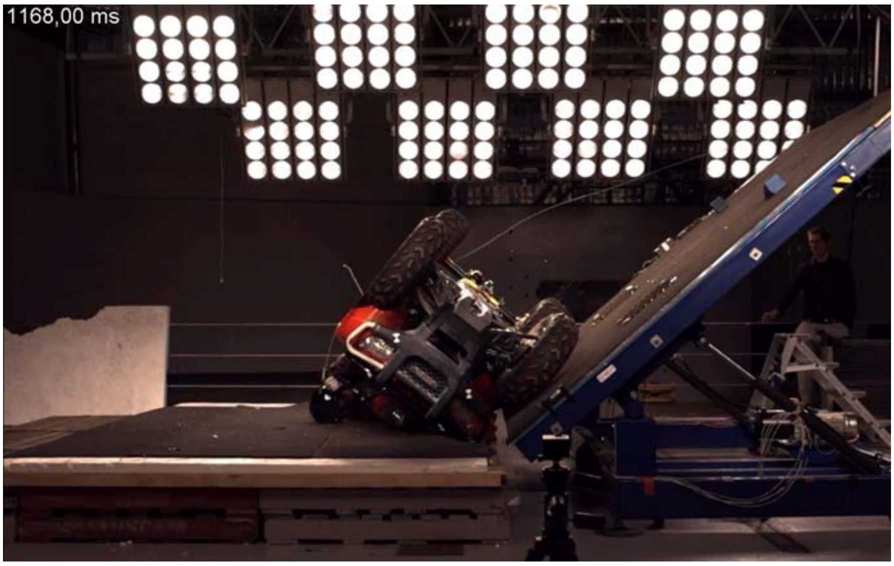


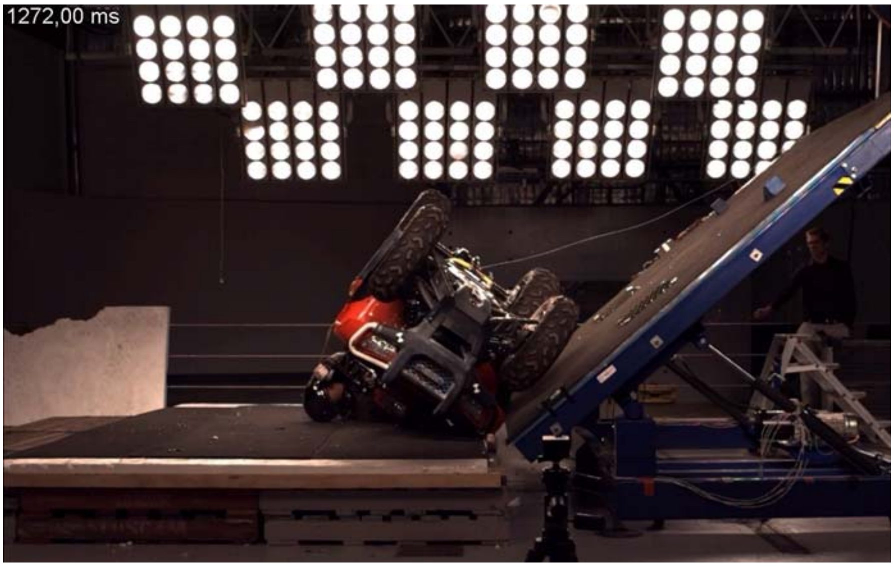


Vehicle and occupant rollover – Test G140077, lateral roll Quadbar

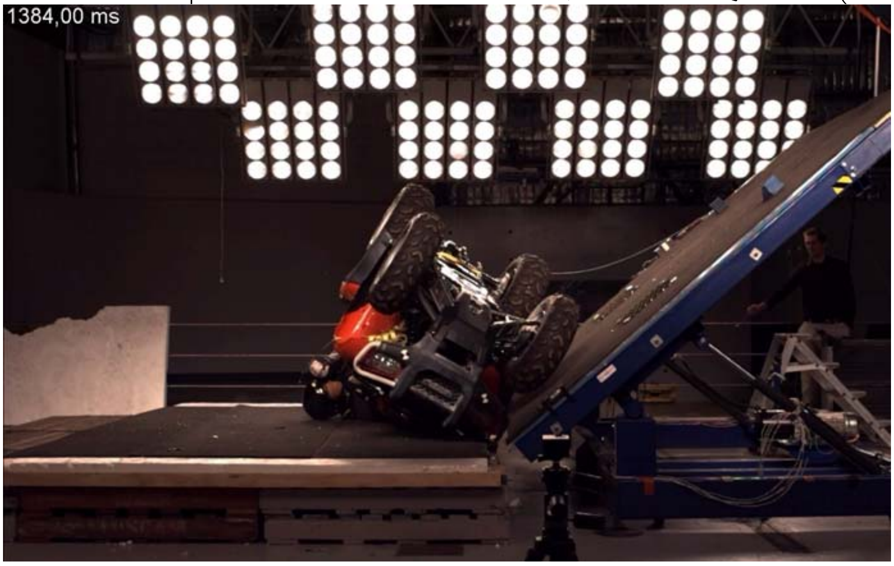


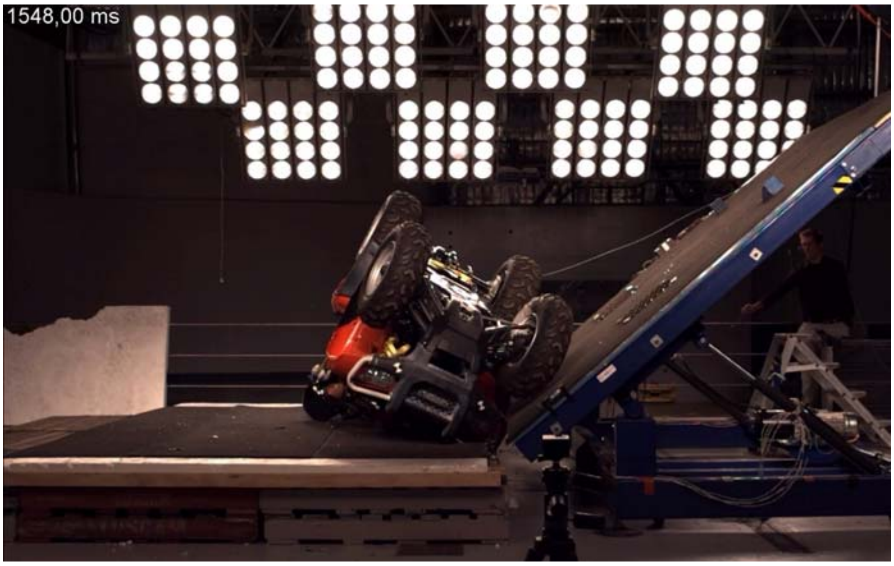
Vehicle and occupant rollover – Test G140077, lateral roll Quadbar (cont.)

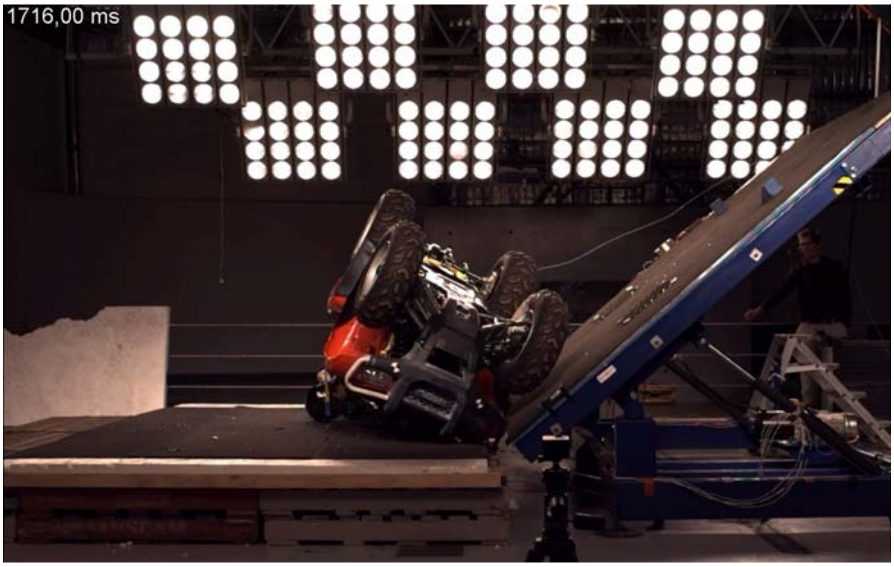




Vehicle and occupant rollover – Test G140077, lateral roll Quadbar (cont.)

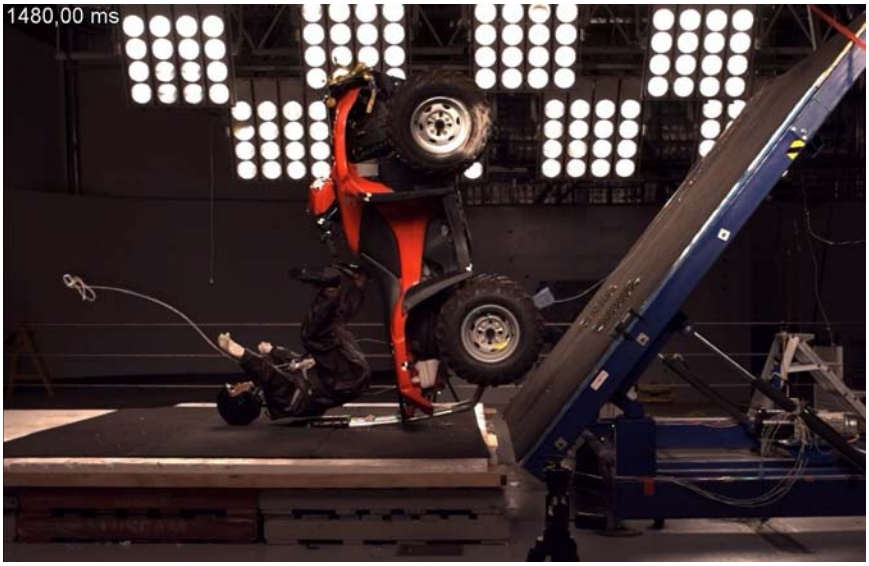






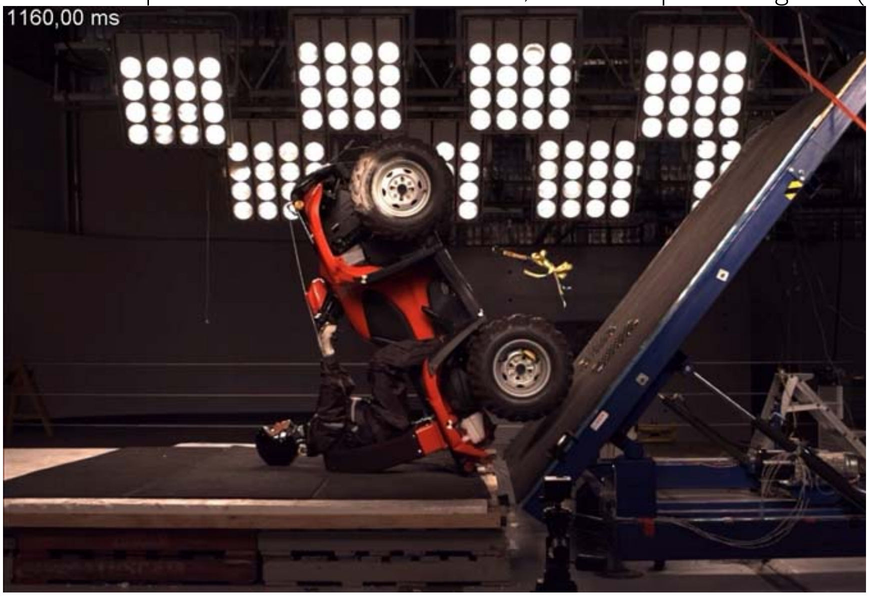
Vehicle and occupant rollover – Test G140078, rearward pitch Quadbar

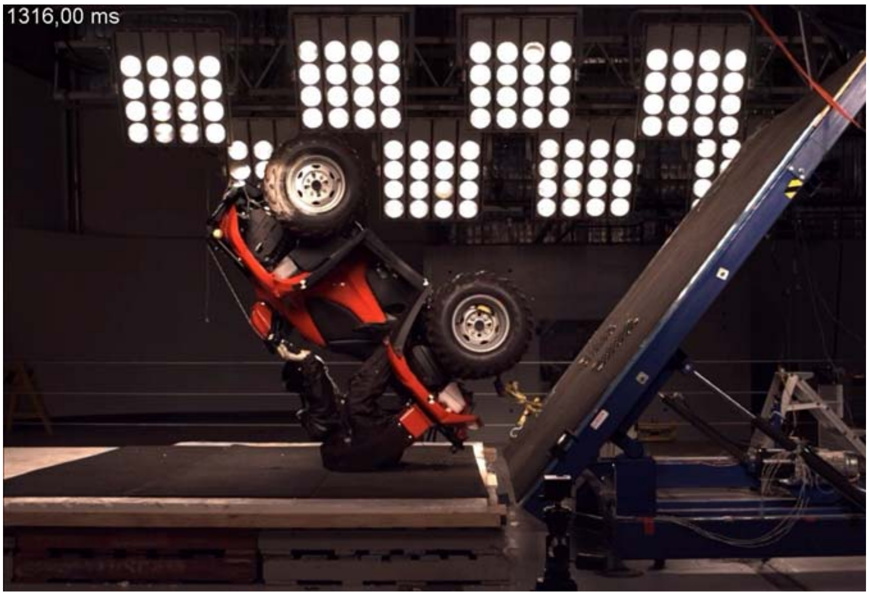
Vehicle and occupant rollover – Test G140078, rearward pitch Quadbar (cont.)



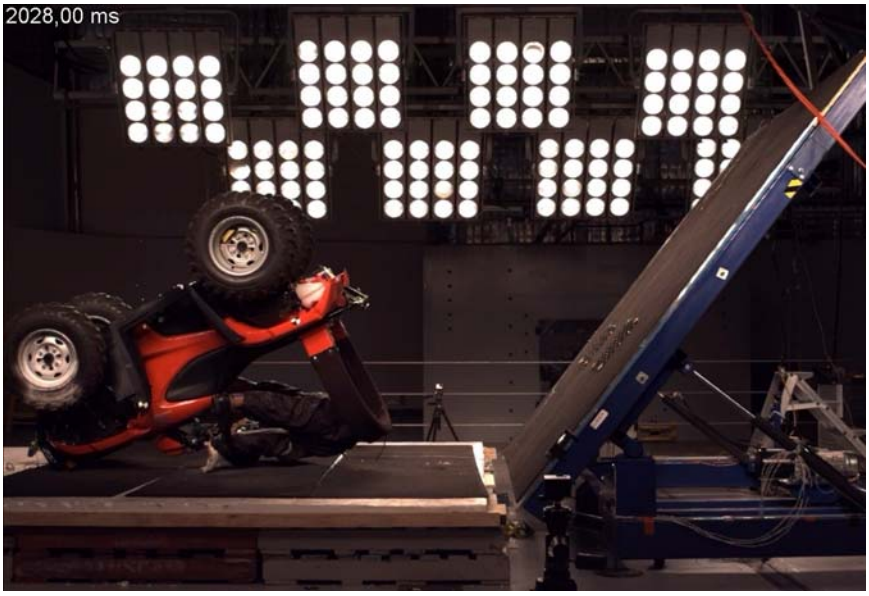
Vehicle and occupant rollover – Test G140079, rearward pitch Lifeguard

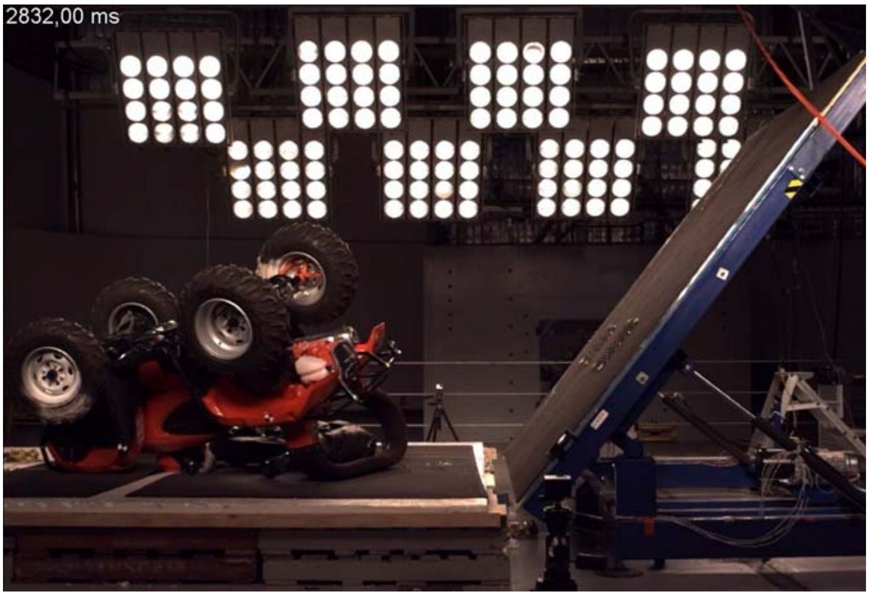
Vehicle and occupant rollover – Test G140079, rearward pitch Lifeguard (cont.)



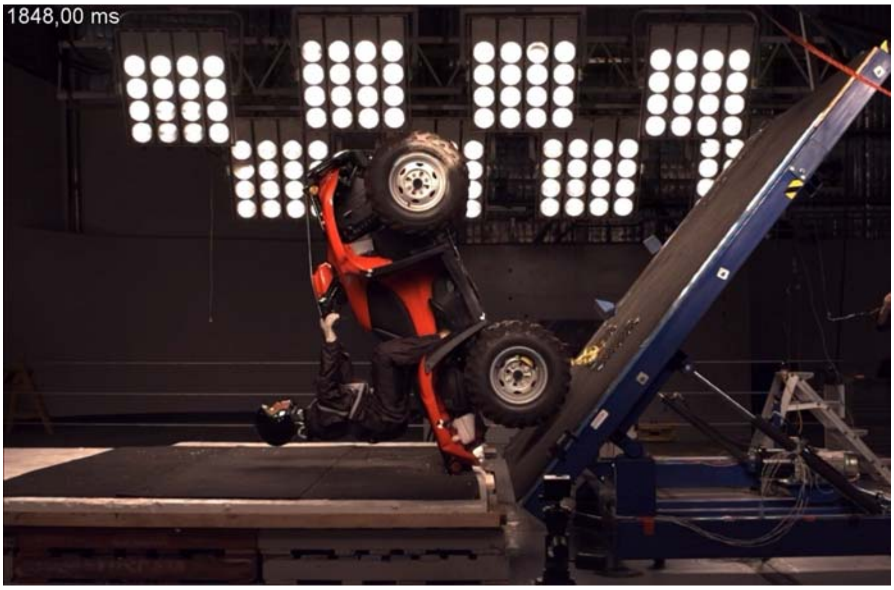


Vehicle and occupant rollover – Test G140079, rearward pitch Lifeguard (cont.)

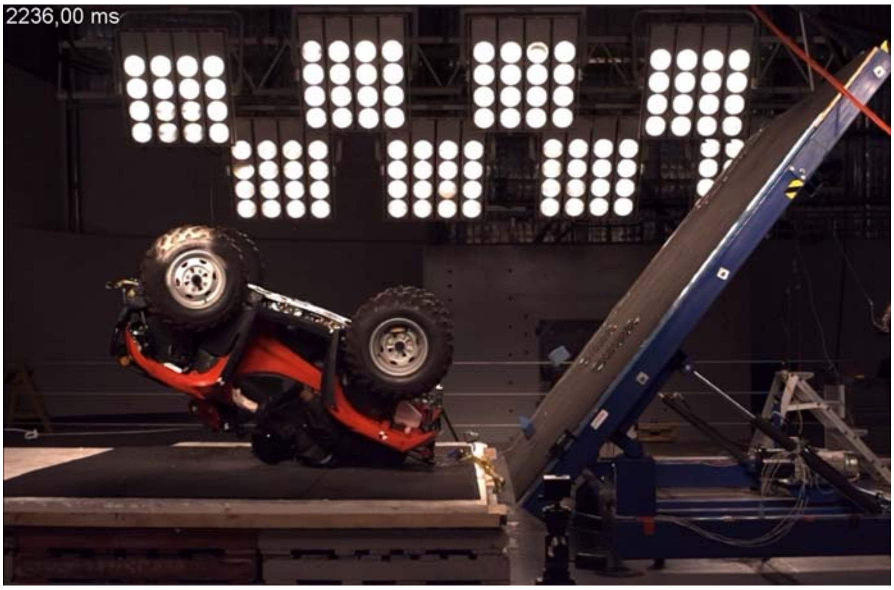




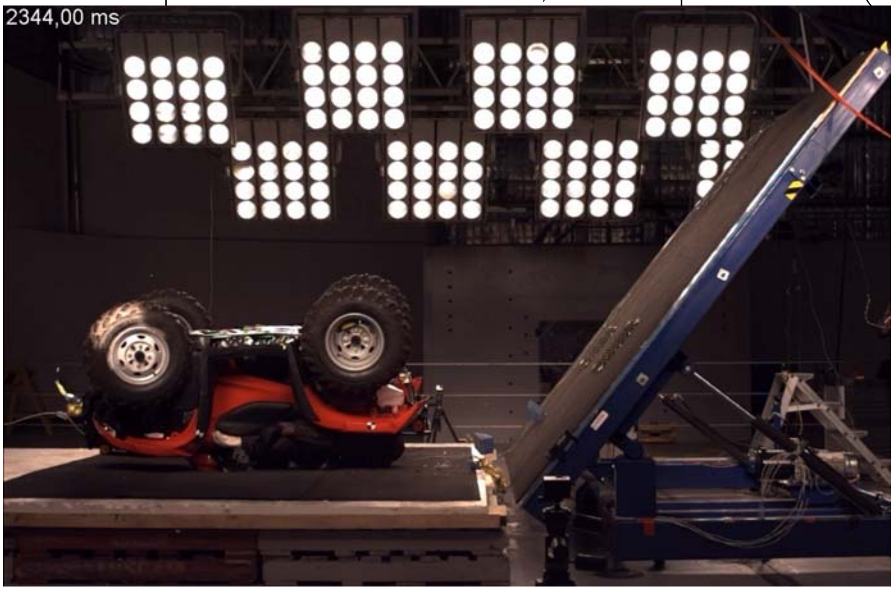
Vehicle and occupant rollover – Test G140080, rearward pitch no CPD

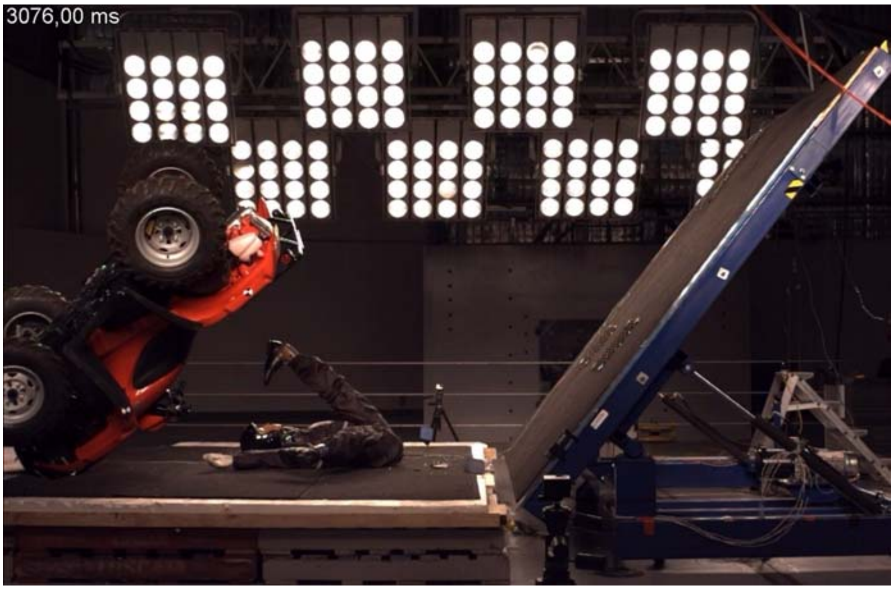


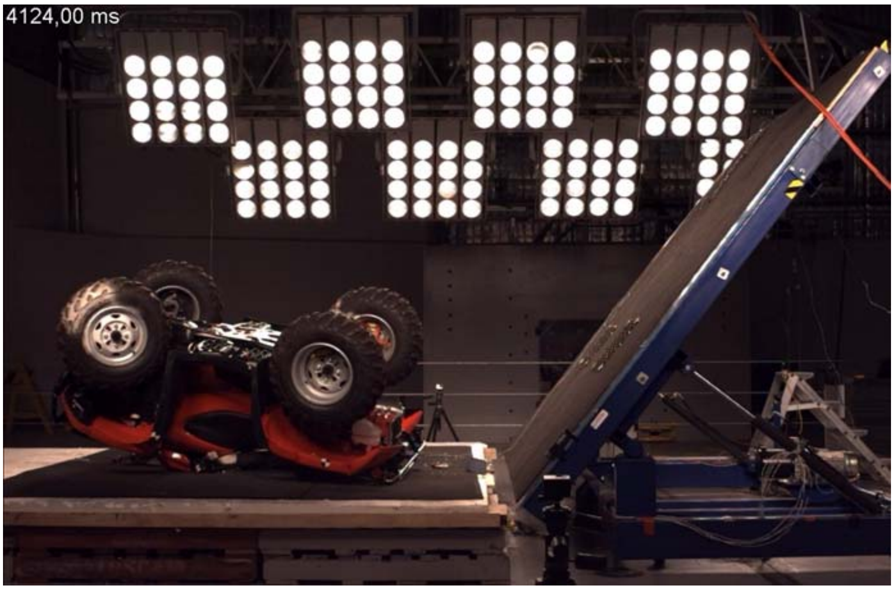
Vehicle and occupant rollover – Test G140080, rearward pitch no CPD (cont.)



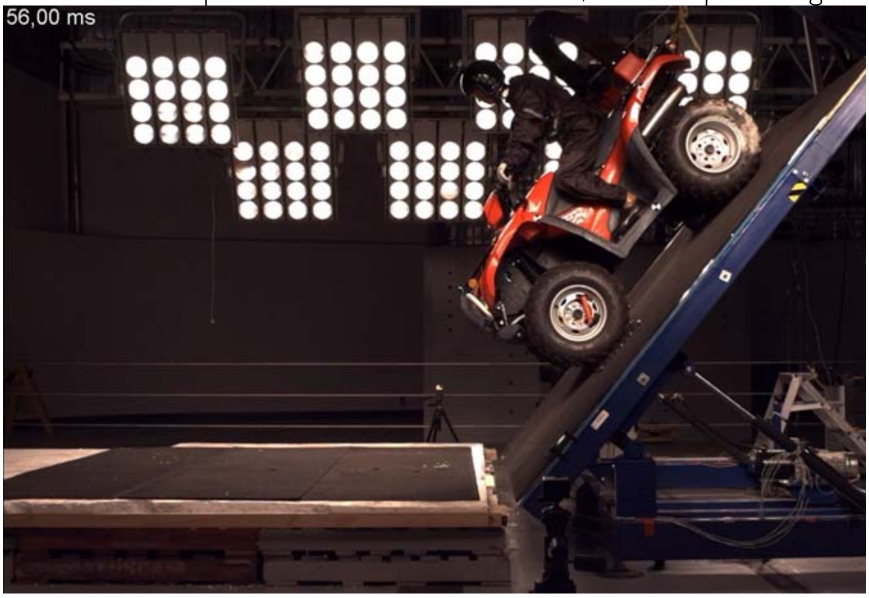
Vehicle and occupant rollover – Test G140080, rearward pitch no CPD (cont.)

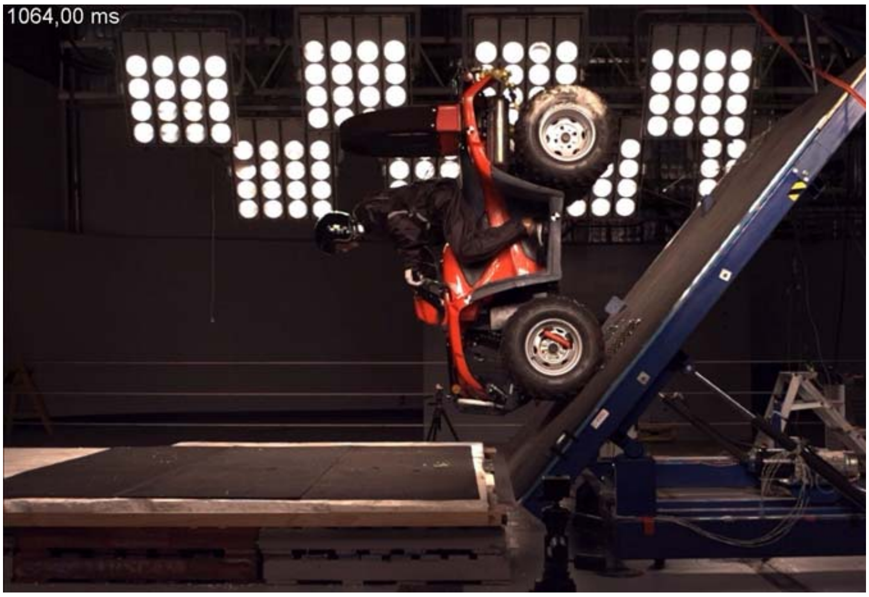


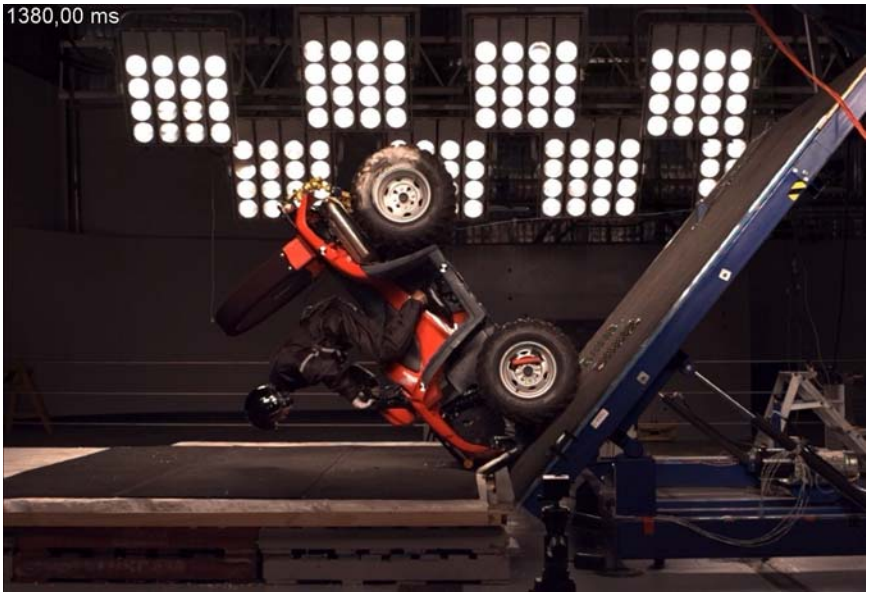




Vehicle and occupant rollover – Test G140082, forward pitch lifeguard

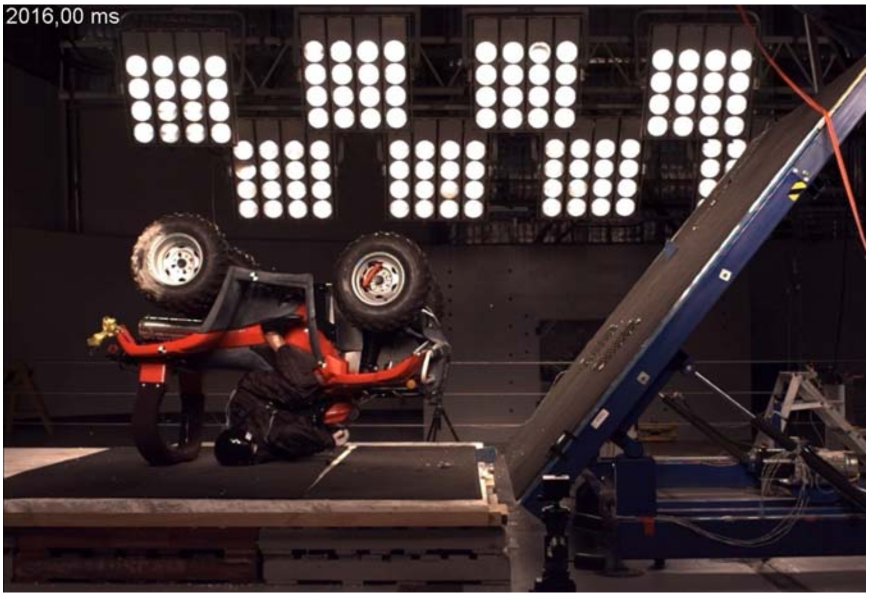


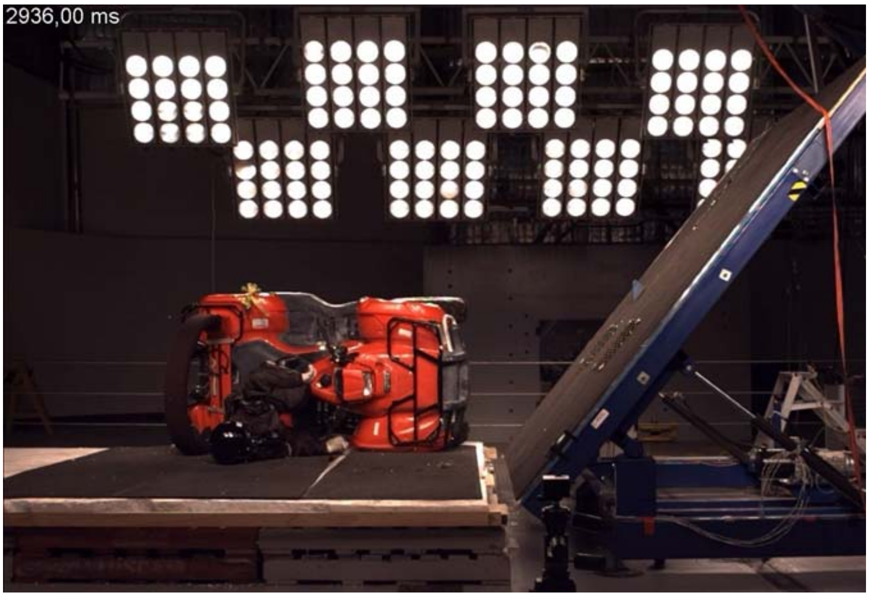




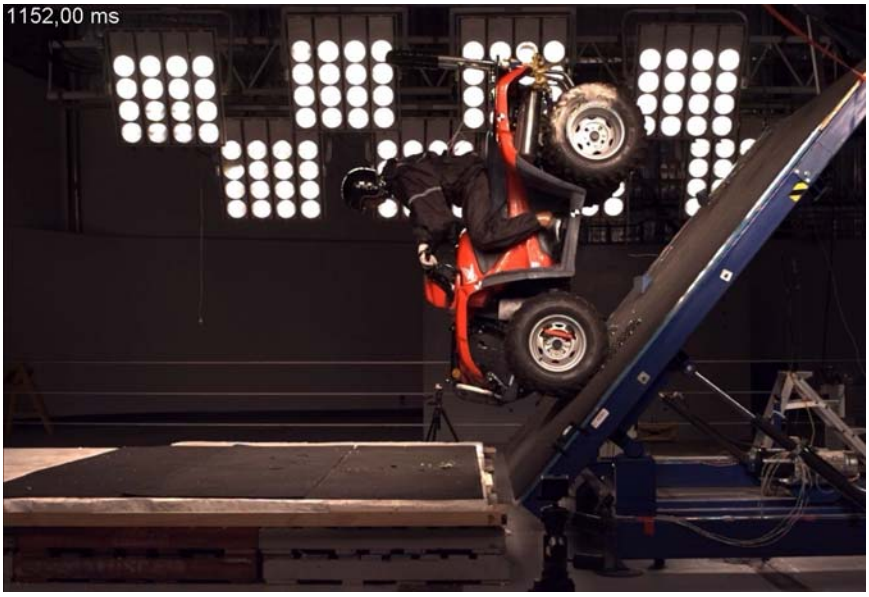
Vehicle and occupant rollover – Test G140082, forward pitch lifeguard (cont.)

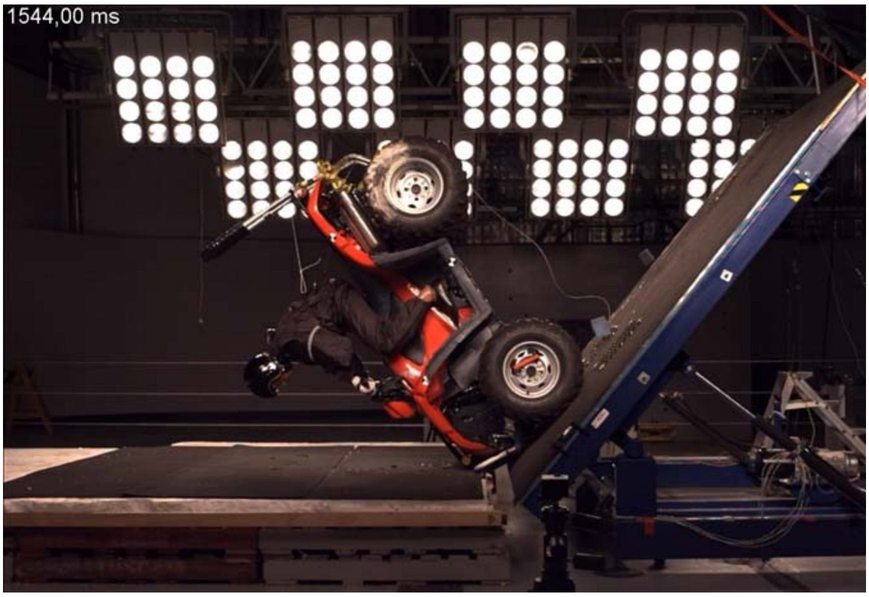
Vehicle and occupant rollover – Test G140082, forward pitch lifeguard (cont.)



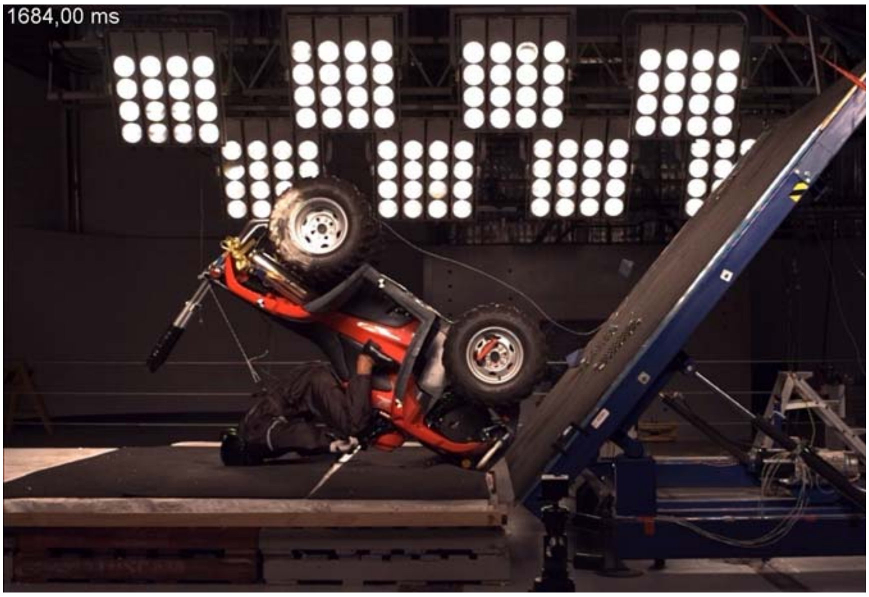


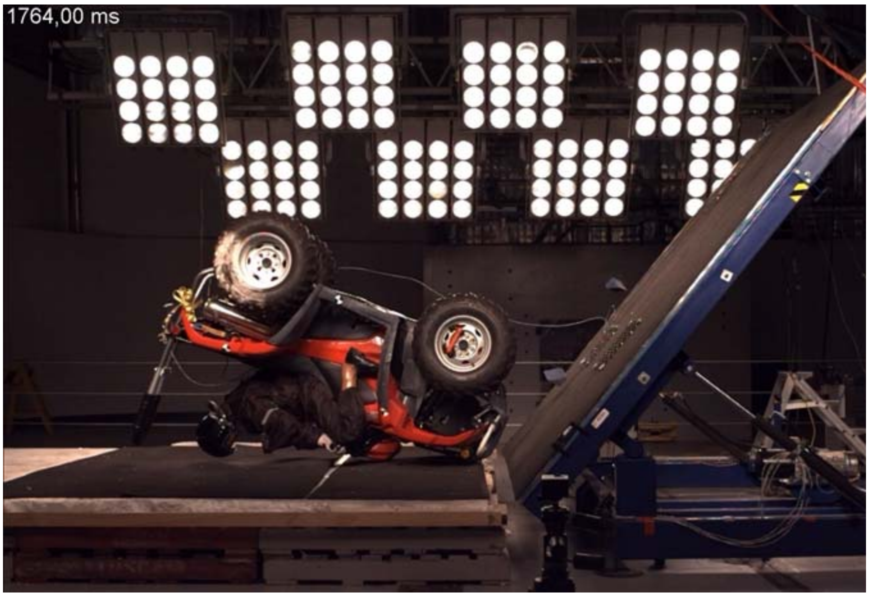
Vehicle and occupant rollover – Test G140085, forward pitch Quadbar



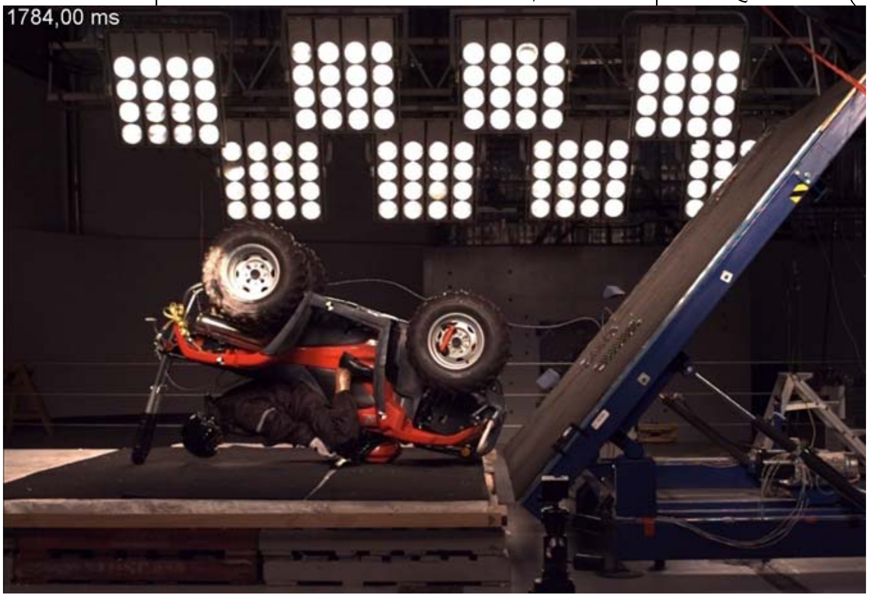


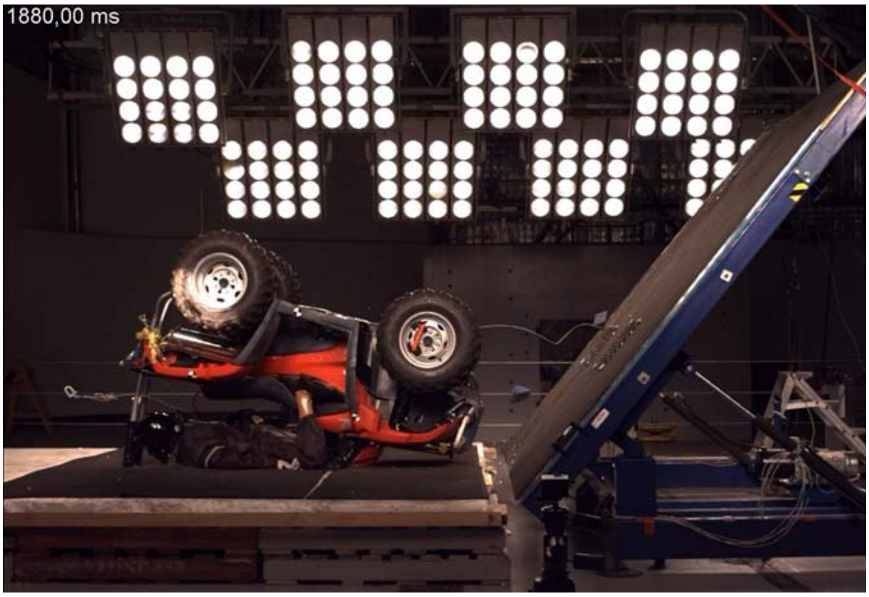
Vehicle and occupant rollover – Test G140085, forward pitch Quadbar (cont.)

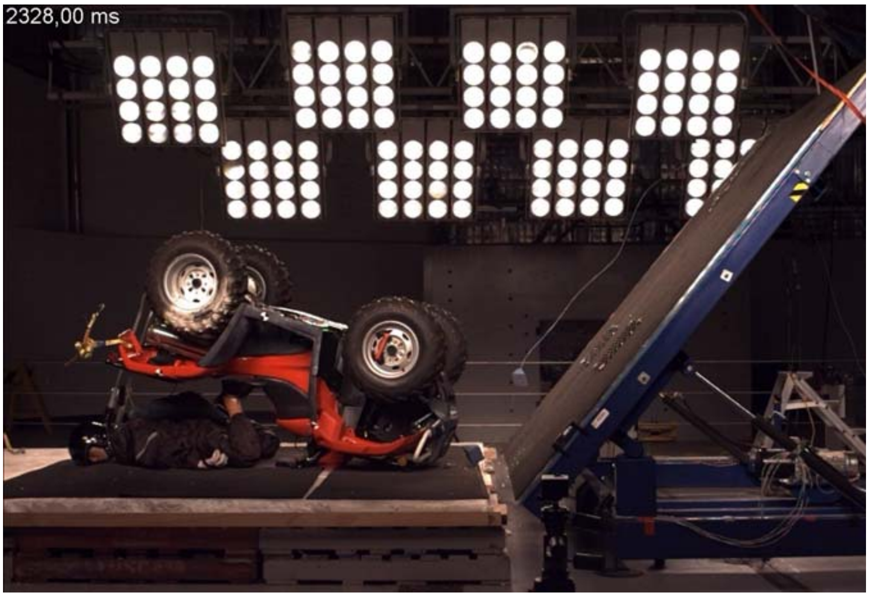




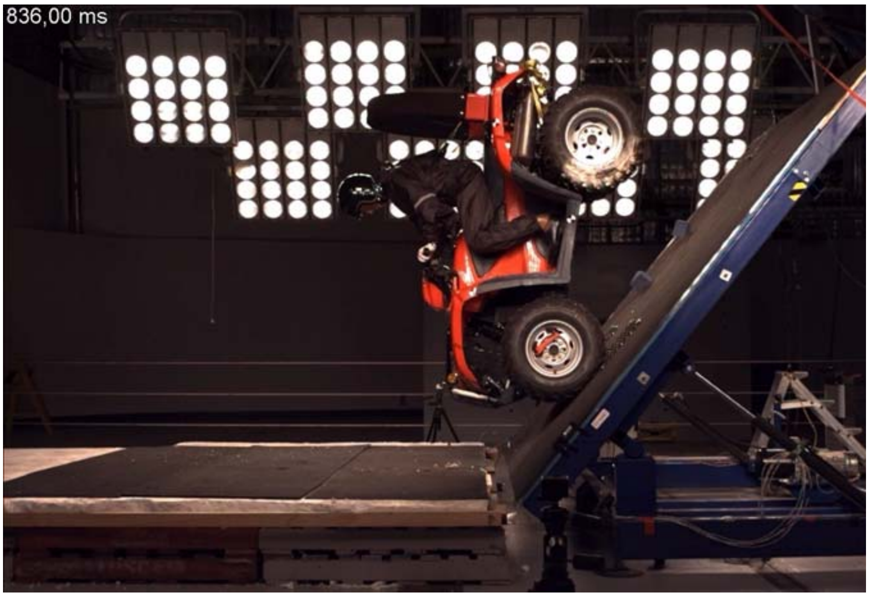
Vehicle and occupant rollover – Test G140085, forward pitch Quadbar (cont.)

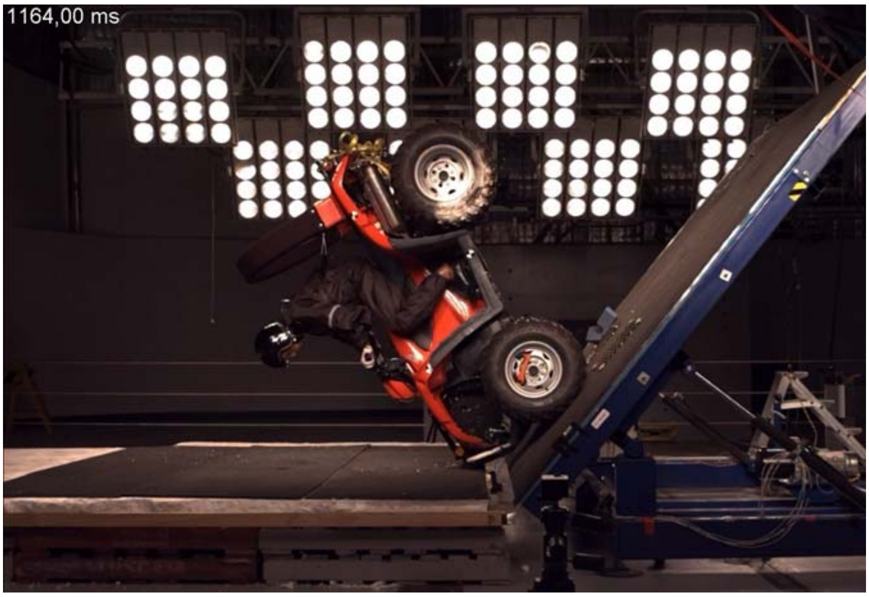




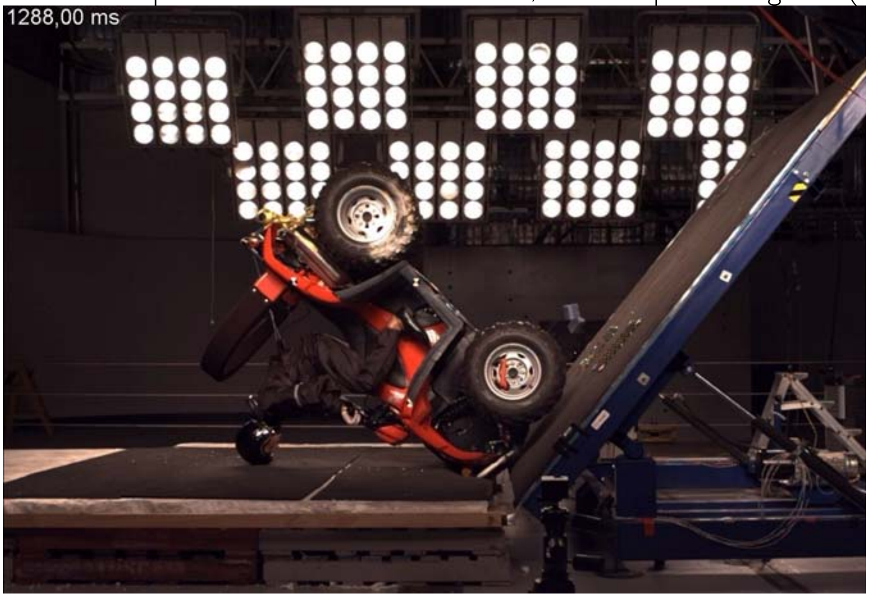


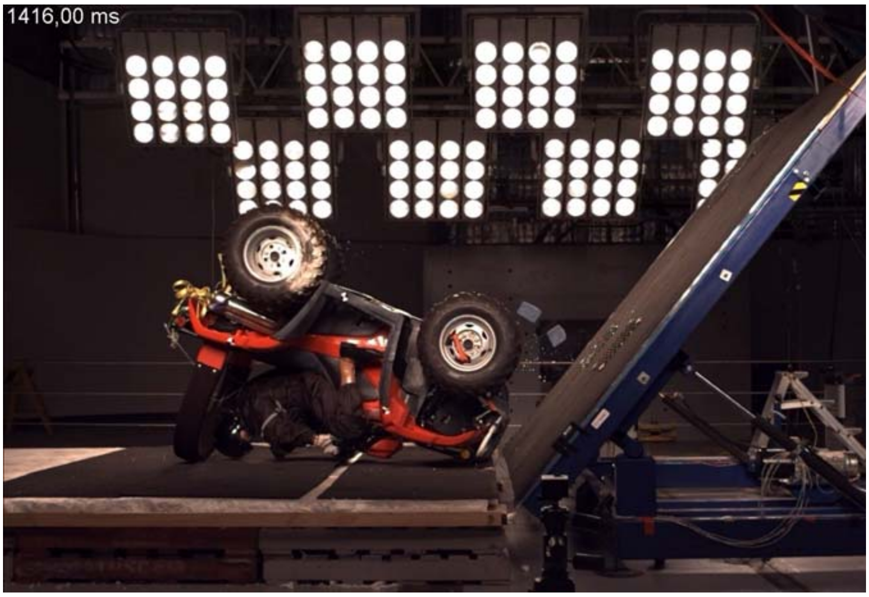
Vehicle and occupant rollover – Test G140087, forward pitch Lifeguard



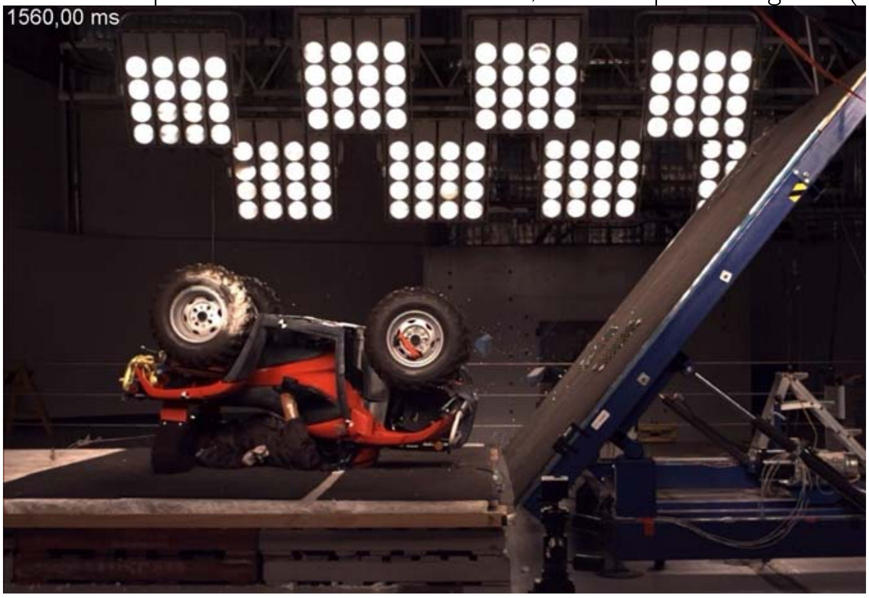


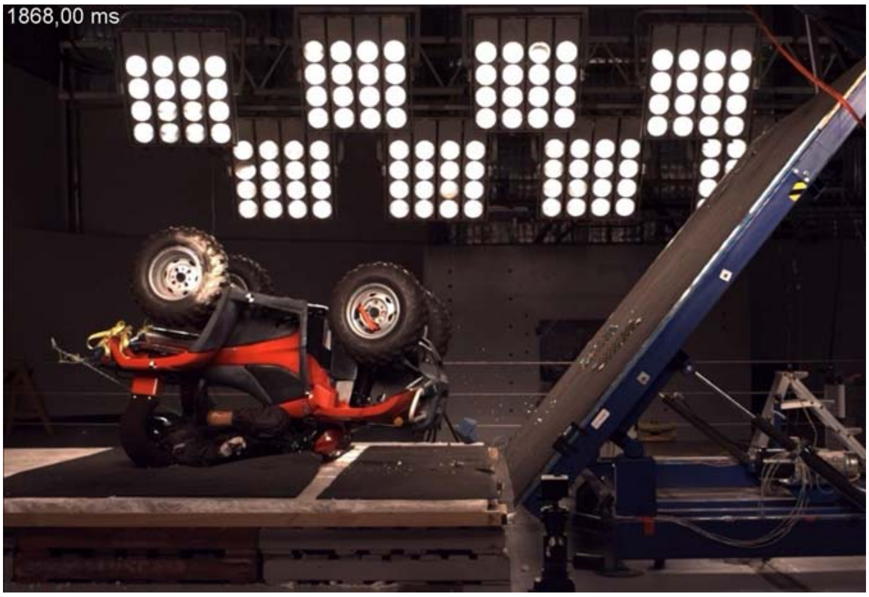
Vehicle and occupant rollover – Test G140087, forward pitch Lifeguard (cont.)

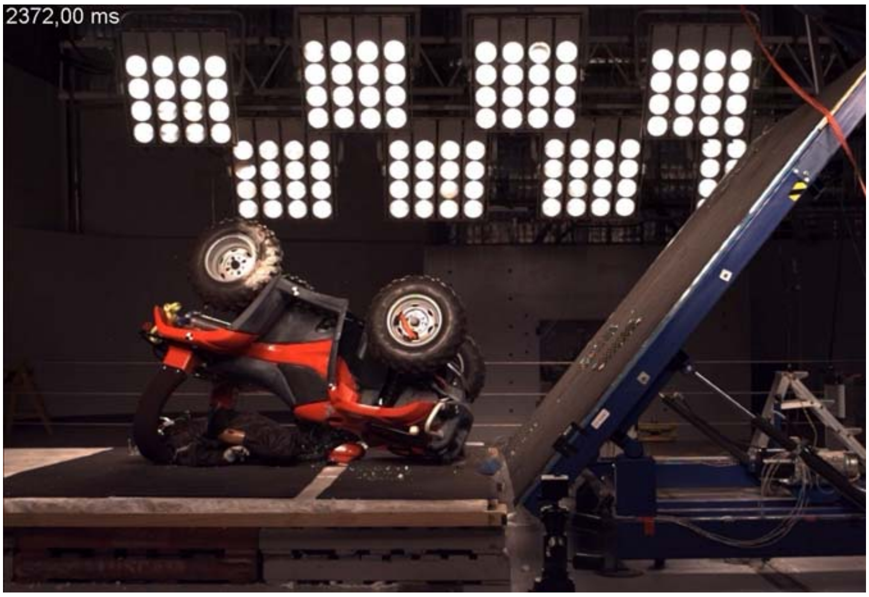




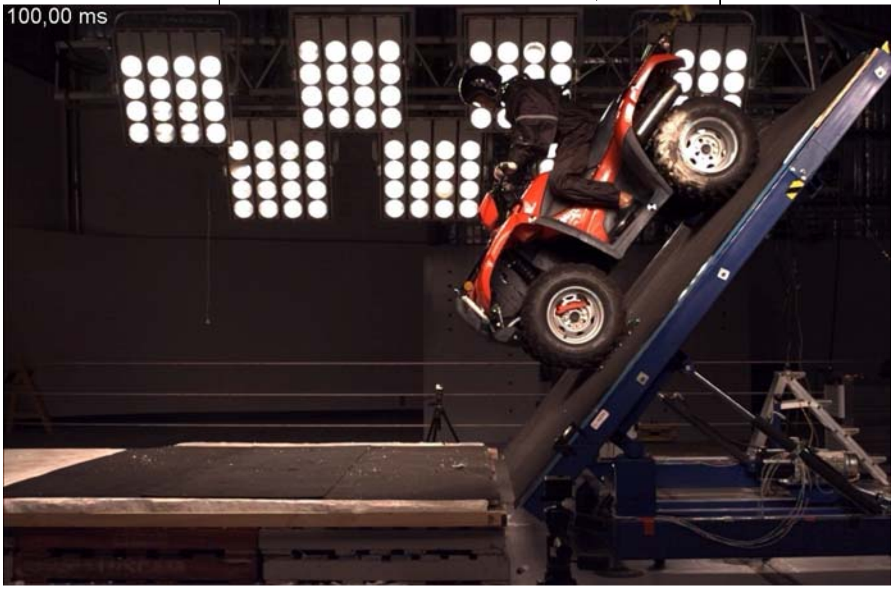
Vehicle and occupant rollover – Test G140087, forward pitch Lifeguard (cont.)

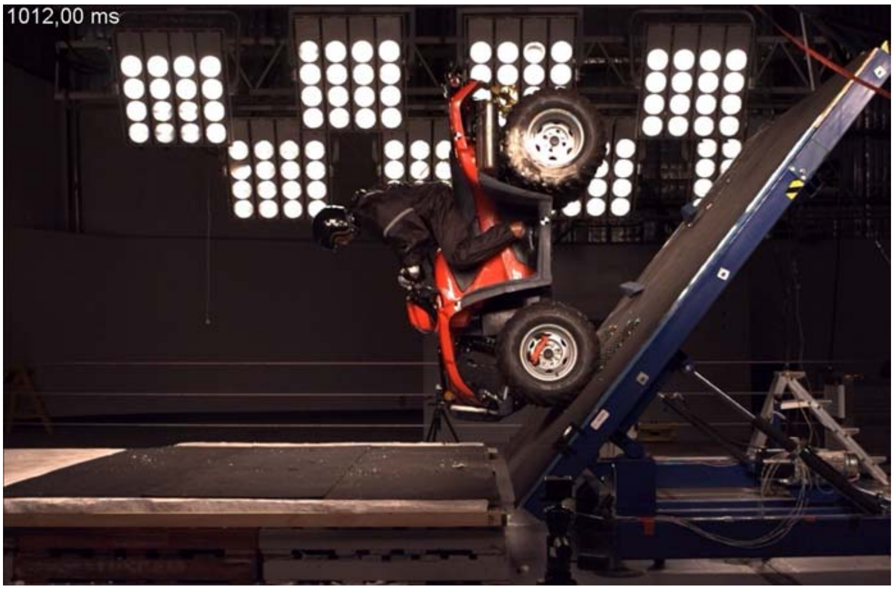


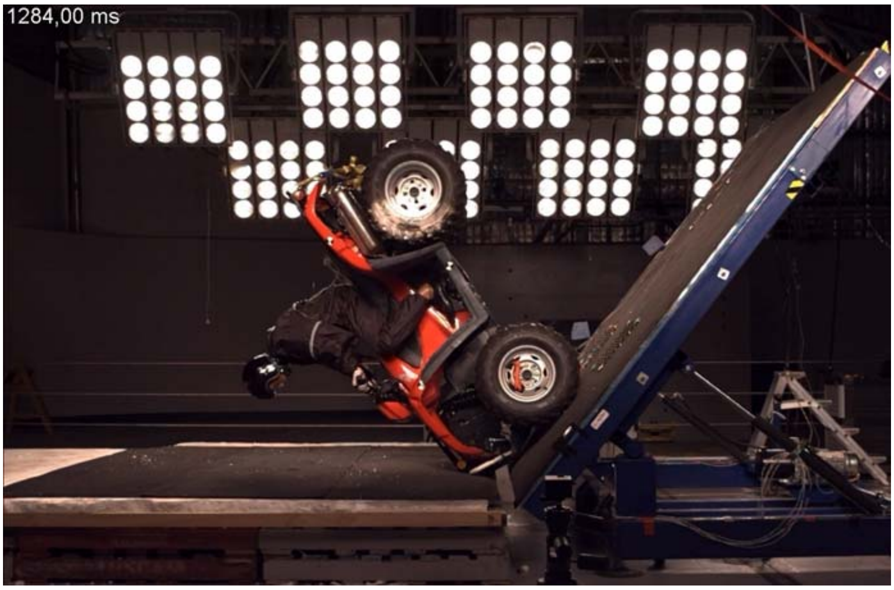




Vehicle and occupant rollover – Test G140088, forward pitch no CPD

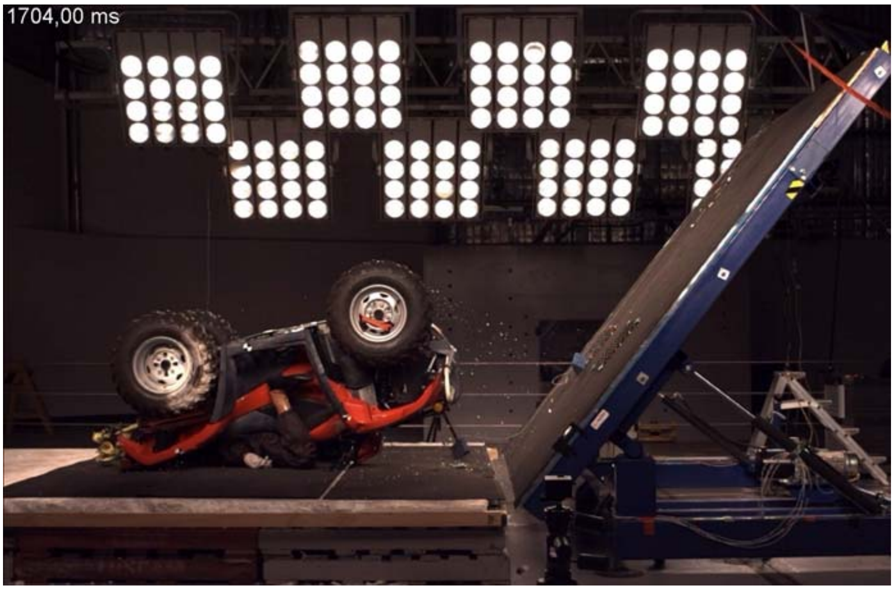


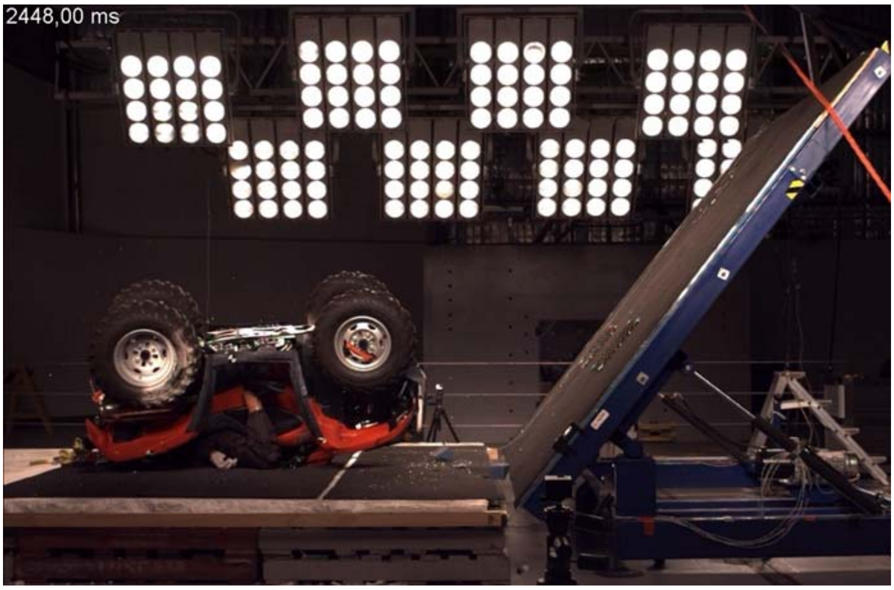




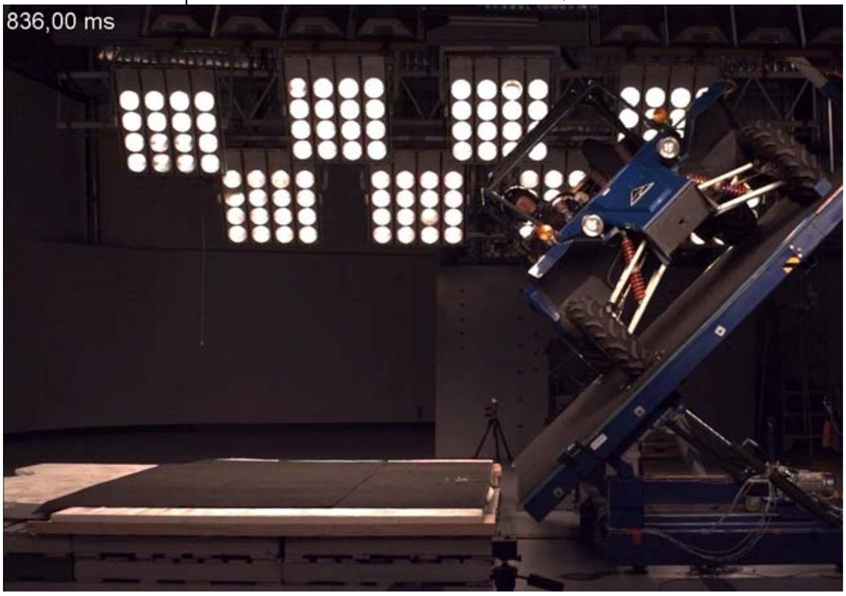
Vehicle and occupant rollover – Test G140088, forward pitch no CPD (cont.)

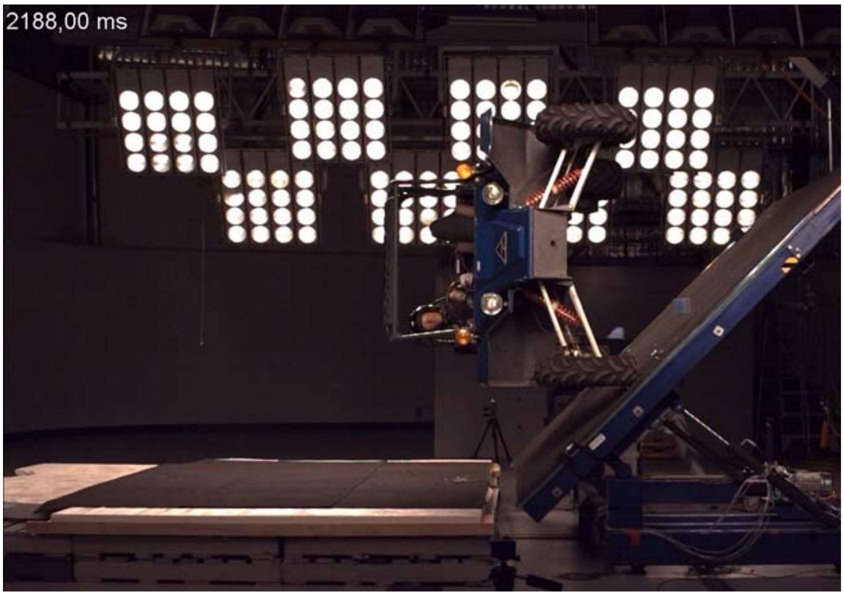
Vehicle and occupant rollover – Test G140088, forward pitch no CPD (cont.)



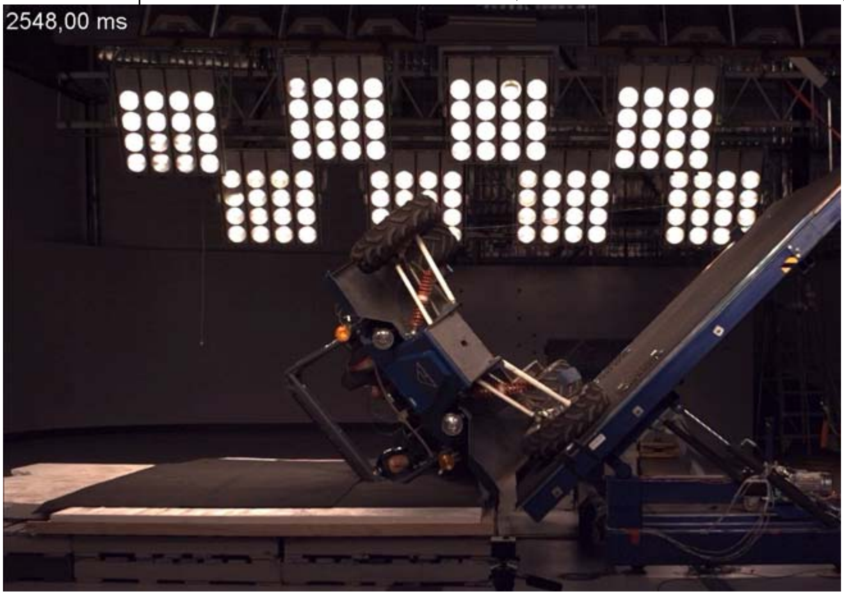


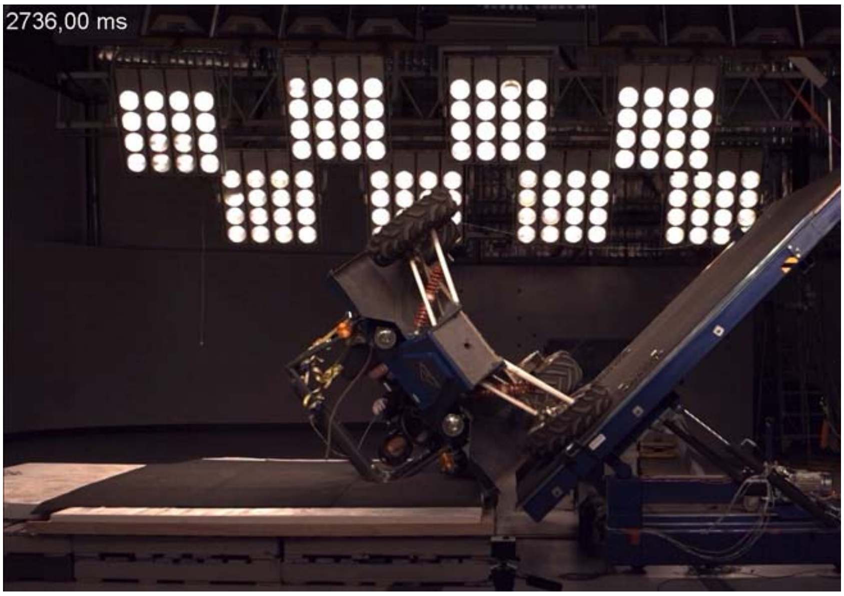
Vehicle and occupant rollover – Test G140107, lateral roll Tomcar TM2

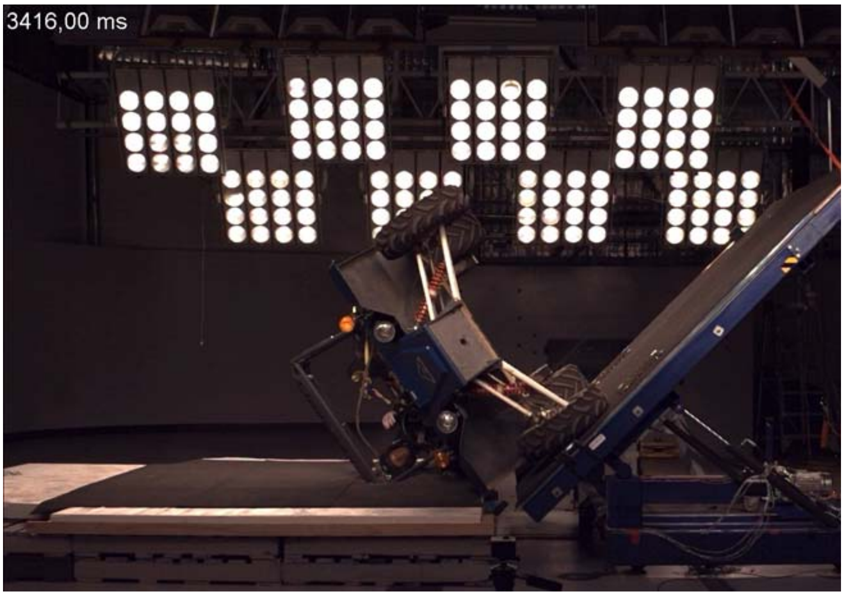




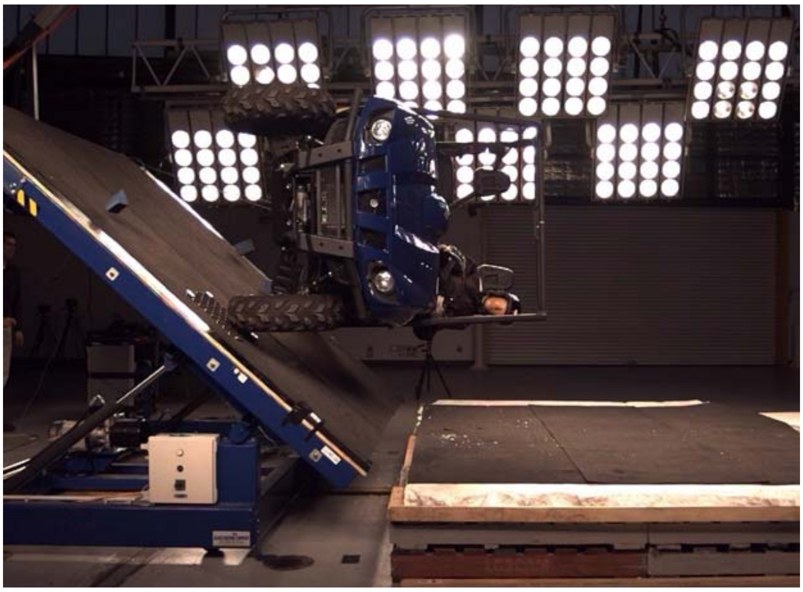
Vehicle and occupant rollover – Test G140107, lateral roll Tomcar TM2 (cont.)

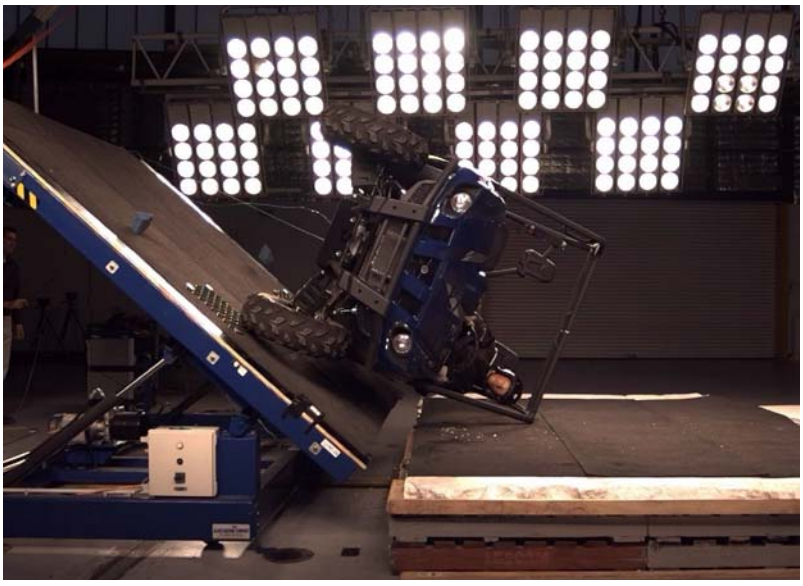




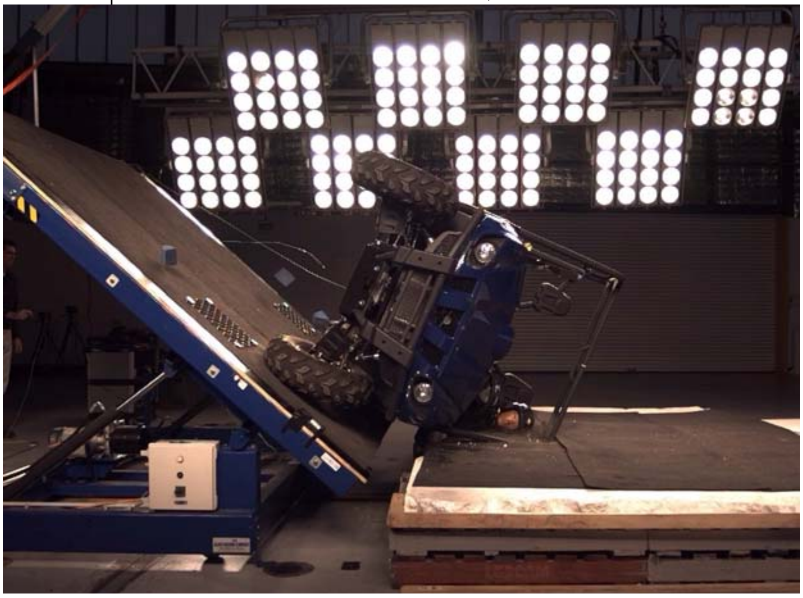


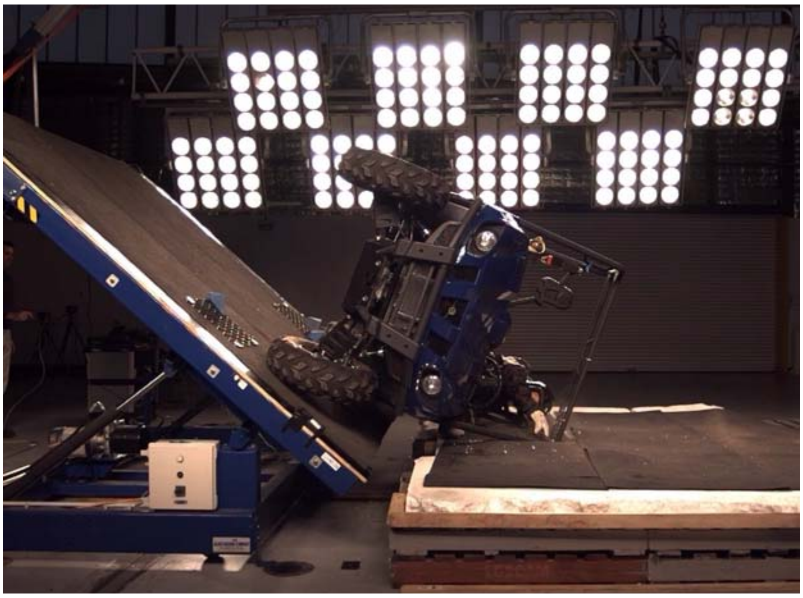
Vehicle and occupant rollover – Test G140108, lateral roll Yamaha Rhino

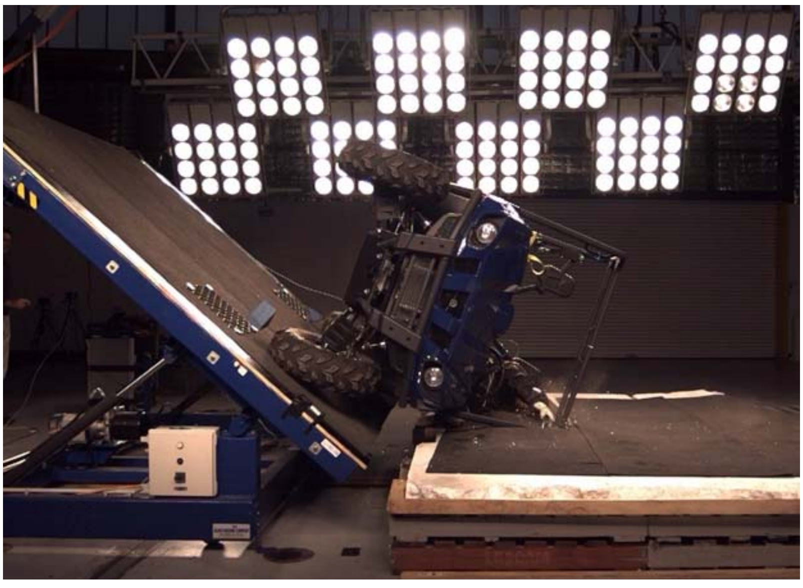




Vehicle and occupant rollover – Test G140108, lateral roll Yamaha Rhino (cont.)





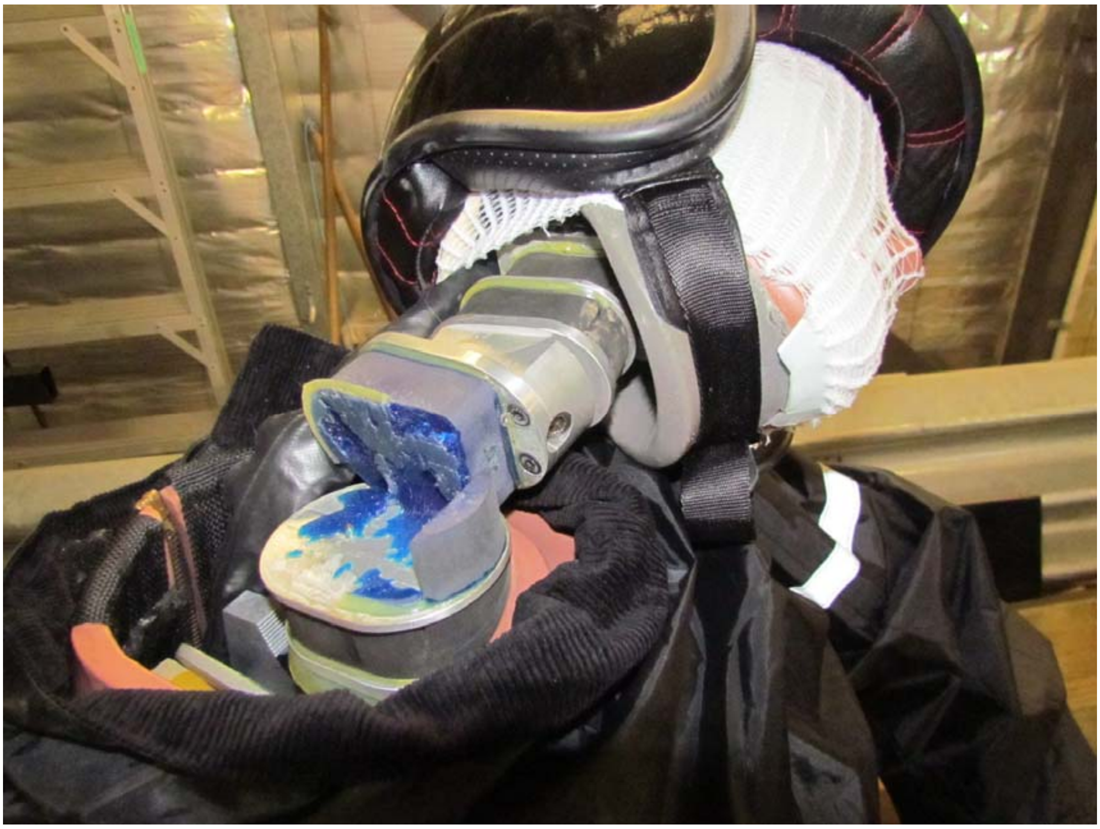


9. Test photographs – Development and research tests


Vehicle and occupant rollover – test setup latroll_00


Vehicle and occupant rollover – test setup latroll_00

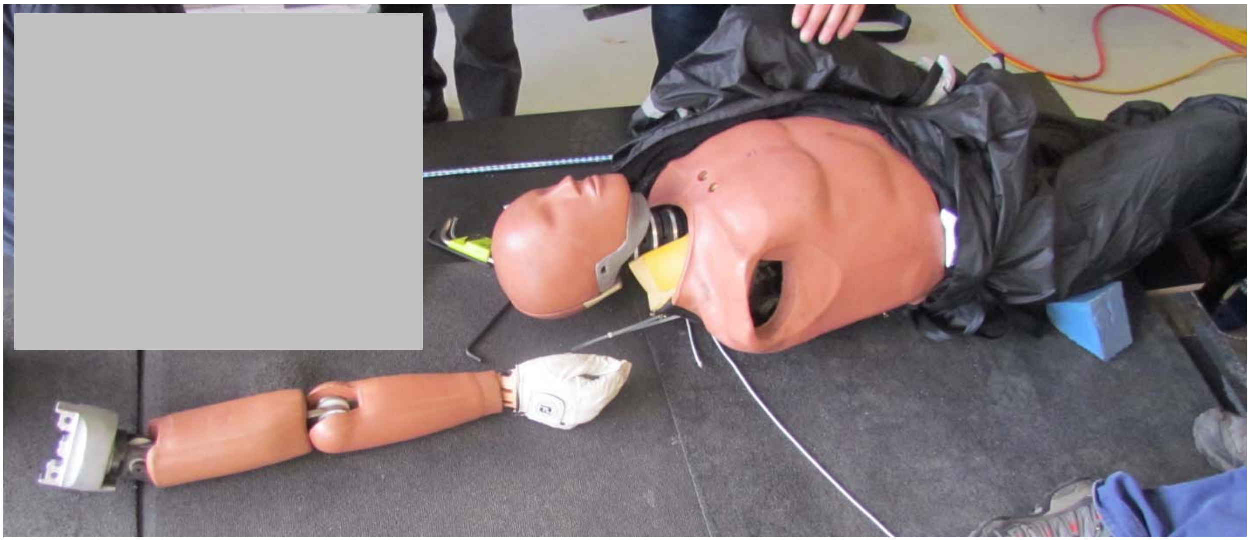
Vehicle and occupant rollover – Test latroll_00 vehicle rest position



Vehicle and occupant rollover – Test latroll_00, damage to MATD neck

Vehicle and occupant rollover – test setup latroll_01

Vehicle and occupant rollover – Test latroll_01 vehicle rest position



Vehicle and occupant rollover – Test latroll_01, damage to MATD right shoulder

Vehicle and occupant rollover – Test latroll_01, damage to MATD left knee varus valgus shear pin

Vehicle and occupant rollover – test setup latroll_02

Vehicle and occupant rollover – Test latroll_02 vehicle rest position

Vehicle and occupant rollover – test setup latroll_03

Vehicle and occupant rollover – Test latroll_03 vehicle rest position

Vehicle and occupant rollover – test setup rearpitch_01

Vehicle and occupant rollover – Test rearpitch_01 vehicle rest position

MATD chest compression – test setup, 500mm drop of quadbike rear tray onto MATD sternum

Appendix E
Instrument details

Appendix Prepared by: Drew Sherry
Appendix Checked by: Ross Dal Nevo

1. Instrument details

Instrument	Manufacturer	Model	Serial number	Instrument number	Test used in
Load cells with digital display	Intercomp	SWI	24032411	TCL3494	Ground contact load
Load cell 5000kg	Precision Transducer	ST-5000	SL57958	T0546	SSV ROPS
Load cell 2500kg	Precision Transducer	ST-2500	88811	T0548	SSV ROPS
String potentiometer	Firstmark	162-3205-C8SS	13063508	T1417	SSV ROPS
TDAS Pro data acquisition system	DTS	TDAS Pro	DM1482	-	SSV ROPS
Motorcycle Anthropomorphic Test Device	DRI	MATD	HGT	-	Vehicle and occupant rollover