Part 2:

DYNAMIC HANDLING TEST RESULTS

REPORT 2

by

Professor Raphael Grzebieta,

Adjunct Associate Professor George Rechnitzer

Mr. Keith Simmons

TRANSPORT AND ROAD SAFETY (TARS)
University of New South Wales
Sydney, Australia

for

THE WORKCOVER AUTHORITY OF NEW SOUTH WALES

92-100 Donnison Street, Gosford, New South Wales 2250, Australia.

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Acknowledgements:

This is the second major test report for the Quad Bike Performance Project, and follows on from Part 1: Static Stability Test Results report.

Although Dynamic Handling testing was initially not part of the Quad Bike Performance Project, it became apparent during the project that adding the Dynamic Handling testing could be done at an incremental additional cost, which fortunately (and gratefully) was able to be funded by NSW WorkCover with support from the NSW State Government.

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The Authors would also like to gratefully thank all members of the Project Reference Group and in particular the following people for their various valuable contributions and comments:

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[1] http://www.enginst.org/

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

- Mr. Paul Vitrano formerly from the Specialty Vehicle Institute of America (SVIA);
- Mr. Neil Storey and Ms. Liela Gato from Safe Work Australia;
- Mr. Charlie Armstrong from the National Farmers' Federation;
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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.

This report, the associated reports and the results presented are made in good faith and are for information only. It is the responsibility of the user to ensure the appropriate application of these results if any, for their own requirements. While the Authors have made every effort to ensure that the information in this report was correct at the time of publication, the Authors do not assume and hereby disclaim any liability to any party for any loss, damage, or disruption caused by errors or omissions, whether such errors or omissions result from accident, or any other cause.

Further Information

Correspondence regarding the Project and Reports should in the first instance, be by email to Professor Raphael Grzebieta, at r.grzebieta@unsw.edu.au or to the WorkCover Authority of NSW, attention Mr. Tony Williams, at Anthony.Williams@workcover.nsw.gov.au.

1. Executive Summary

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.

This is the second major test report for the Quad Bike Performance Project (QBPP), and follows on from Part 1: Static Stability Test Results (Report 1), for the 17 vehicles (16 production vehicles and one prototype Quad bike) and Operator Protection Devices tested (Figure 1 and Figure 2). The reader is referred to Report 1 for the detailed introduction and background to the Project (also see Rechnitzer et al. 2013), which is not repeated here. Hence, this Report provides a summary of the methodology used, key findings and analyses from the Dynamic tests and its significance to the Project, Quad bike and SSV safety, and ratings.

The industry (through FCAI) claim that there is currently no incident statistical data available or collected to enable determining the correlation (if any) between a vehicle's handling characteristics and collision and injury risk. The Authors strongly disagree with this claim and have set out the basis for this in Section 2.2.1 Introduction.

The Dynamic Handling tests were carried out at Crashlab and the grounds at Sydney Dragway, Eastern Creek race track. Over 546 tests were carried out. The full Crashlab Test Report (written by Mr. Drew Sherry and Mr. Ross Dal Nevo), the methods used and all test results for each of the sixteen production vehicles tested are provided in Attachment 1.

Following on from the Static Stability test program for the 17 vehicles (includes the prototype Quad bike), the dynamic test program provides the second arm of the assessment and rating of production Quad bikes and SSVs for stability and handling. Improvements in Quad Bike and SSV handling has been highlighted by authors such as Roberts (2009) and others as being practical means to reduce crash and rollover risk.

The Part 1: Static Stability Test Results (Report 1) and Part 2: Dynamic Handling Test Results (Report 2) are combined with Part 3: Rollover Crashworthiness Test Results (Report 3) of the Project involving testing the crashworthiness of the 17 vehicles, with the objective of developing an Australian Terrain Vehicle Assessment Program (ATVAP) relative rating system to inform consumers purchasing vehicles for the workplace and farming environment.

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 (2014) and Mitchell (2014) and some further analysis by the co-Authors Grzebieta, Rechnitzer and Simmons. All these 'final' reports are dated January 2015. However, it should be noted that the first drafts of these reports were completed much earlier and parts were subsequently amended following feedback from NSW WorkCover Authority, Industry and International Reviewers. First draft dates are provided in Table 1 in Report 4: (Final Project Summary Report: Quad Bike Performance Project Test Results, Conclusions and Recommendations).

As mentioned above, the dynamic test program consisted of 546 tests, in three different dynamic tests series (see Attachment 1) all relating to vehicle control and handling characteristics which are likely to improve a driver's/ rider's vehicle path control and the vehicle's resistance to rollover:

1. **Steady-state circular driving behaviour dynamic tests** to determine each vehicle's limit of lateral acceleration and the understeer/ oversteer characteristics. The Steady-state circular driving behaviour test consisted of slowly accelerating each vehicle from rest whilst tracking around a circle of 7.6m radius. The vehicle was accelerated until it either: lifted the two inside tyres off the ground and tipped up; could no longer stay on the circle; or the rear of the vehicle slid out causing the vehicle to point towards the inside of the circle; or the vehicle could not travel any faster.

2. **Lateral transient response dynamic tests** to determine each vehicle's time taken to respond to steering manoeuvres. The test consisted of driving the vehicle in a straight line at a velocity of 20km/h and then rapidly inputting a steering response to generate a lateral acceleration of 0.4g. The yaw rate to steering response time was recorded.

3. **Bump obstacle perturbation tests** to determine each vehicle's response characteristics while riding over asymmetric bumps in terms of change in steering direction or displacement and lateral and vertical acceleration of the test dummy. These tests represent the ability of the vehicle to ride over ground obstacles that could in some circumstances precipitate loss of control and consequential rollover.

   The test consisted of towing the vehicle in a straight line towards a 150mm high semi-circular 'bump' object lined up with either the right or left vehicle track. Each vehicle 'free-wheeled' over the obstacle unaffected by the tow system. An Anthropomorphic Test Device (ATD) was positioned on the vehicle with the pelvis acceleration recorded.

The steady-state circular driving behaviour and lateral transient response tests were conducted at Sydney Dragway, Eastern Creek, NSW Australia. The bump obstacle perturbation tests were conducted at Crashlab, Huntingwood, NSW, Australia.

While most testing was conducted on a dry asphalt surface (for reproducibility purposes), to identify the effects of different surfaces on handling, some testing was also conducted on dry grass and loose bluemetal over compacted roadbase. Each test configuration was tested three times to establish result repeatability. Results tables are contained in the Crashlab Report, Appendix C (Attachment 1). Results show and confirm that Quad bikes can be reliably tested and rated for handling characteristics using such surfaces. Of course there are other surfaces and soil conditions such as wet mud, sand, tilled soil, etc., which may not be represented by these tests.

The key findings from the dynamic tests are:

1. For the Quad bikes, the measured minimum limit of lateral acceleration at tip up, with rider hips centred and buttocks in contact with the seat, was in the range of 0.36g to 0.55g, and for each Quad bike was less than the Tilt Table Ratio (TTR). Such tipping up can be counteracted to some degree by the rider moving their body around relative to the vehicle ('Active Riding'). However, depending on the vehicle and rider, at best a 10%-20% gain in regards to increasing TTR might be achieved. The tests carried out and results presented in this report are for a worst case scenario where the rider was not 'Actively Riding', i.e. in the majority of farm related fatalities. The circle tests validated that the tilt-table static stability TTR value provide valid measures of the lateral stability (i.e. level of rollover resistance) of Quad bikes.
2. All Quad bikes limit of lateral acceleration on these test surfaces in a quasi-constant speed steady turning condition, occurs by tipping up onto two wheels, and is a precursor to rollover or loss of control – that is, a loss of stability.
3. For the SSVs, these vehicles showed higher limits of lateral acceleration, i.e. higher rollover resistance) than the Quad bikes, and did not tip up except for the Yamaha Rhino. These results are generally consistent with the Static Stability tilt-table tests, which showed higher stability metrics for the SSVs.
4. The Authors note that the most recent US CPSC's (2014) study recommends an increase in lateral stability in the current standards, to require a minimum lateral acceleration at tip up for SSVs of 0.70g in a 30 mph (48 km/h) J turn test to reduce the risk of rollover.
5. The three Quad bikes that were tested on dry asphalt and dry grass displayed very similar handling characteristics and tipped up at similar lateral acceleration values on both surfaces. Testing of Quad bikes on an asphalt surface did provide relevant, reproducible performance characteristics.
6. The Honda TRX250 Quad bike[3] was used as a representative Quad bike for comparing the effects of surface type, load combinations and 'Active Riding' on lateral stability. With Active Riding (on asphalt), the dynamic stability values increased by approximately 13%, from 0.46g up to 0.52g. The maximum value was very similar to the tilt table TTR (without Active Riding) of 0.51g.

[3] A 'representative' Quad was selected for these comparison tests. It was beyond the scope and budget of this dynamic test program to be able to test all of the 17 vehicles in all load and surface combinations. As noted well in excess of 546 tests were conducted in this dynamic test program alone.

7. The example Quad bike (Honda TRX250) when tested with the Quadbar and Lifeguard OPDs, showed only a minor change in limit of lateral acceleration (0.46g down to 0.45g). The Quick-fix OPD was not tested as it was not recommended for fitment as an OPD to any Quad bike in Part 1: Static Stability Test Results report. This was because of the Quickfix's effect on reducing a Quad bike's TTR by up to 14%. The Quickfix unit also restricts a rider from standing upright on the vehicle limiting the ability to correctly use Active Riding techniques.
8. The results overall obtained show that most Quad bikes tested for this program have an oversteer characteristic, which is not a favourable characteristics for most workplace riding situations. Notably, the Honda TRX700 recreational Quad bike, showed a light understeer characteristic of around 2 degrees per g through to above 0.5g. This is considered a very good steering characteristic and demonstrates that it is quite possible to design the steering system of a Quad bike to produce the recommended handling results for a work place environment.
9. In order to handle well (consistently and safely) and reduce the risk of a loss of control crash occurring, a Quad bike or SSV, like any other self-propelled vehicle, should have a slight understeer characteristic when excited between 0.1g and 0.5g lateral acceleration.
10. All vehicles tested unloaded on asphalt had steering response times of less than 0.3 seconds, with a significant number of the vehicles displaying steering response times of less than 0.2 seconds (see Figure 23), which is generally considered to be satisfactory.
11. The 'bump tests' identified, possibly for the first time, a significant mechanism where riders on some Quad bikes may have lost control while traversing moderately sized bumps (similar to half-buried logs, drainage or irrigation pipes, small mounds, furrows, rocks, rabbit holes, etc.), which could have led to a rollover and resulted in their being pinned by the Quad bike as was observed in a large number of fatality cases analysed by the Authors. Although no full loss of control event was recorded with the human test rider obviously for safety reasons, riders as well as the Quad bike itself were displaced substantially laterally similar to what was observed with the crash test dummy tests (see Figure 16 and Attachment 1 Crashlab Report). In addition, and as a result, in the bump tests, the passive crash test dummy can lean away from the Quad bike, pulling on the far-side handle bar, further increasing the Quad bike's turning rate, leading to potential rollover. All of the SSVs traversed the bump satisfactorily, with a low level of rider or vehicle perturbation. This potential loss of control mechanism as observed in the bump tests is currently being explore by a postgraduate David Hicks as part of his PhD studies.

In contrast to the Quad bikes, and based on these tests, SSVs had more 'forgiving' handling and higher stability characteristics (i.e. higher resistance to rollover), and are less reliant on operator vehicle handling skills, i.e. the tested SSVs have a higher error tolerant threshold in terms of their handling and stability when operated in a typical farming environment.

Observations from the Dynamic Handling Overall Rating Index

Results from the Dynamic Handling tests provide sufficient discrimination between vehicles for the range of vehicles tested (Quad bikes and SSVs) to use as a basis for a rating system.

The SSVs, except for one model (14 points) all have a higher Dynamic Handling Overall Rating Index with points from 18 to 20, compared with 10 to 12 for the work Quad bikes. One of the recreation Quad bikes has a high rating of 17 points. The maximum possible index value is 25 points.

These dynamic tests were also innovative in that they showed that Quad bikes could be subject to scientifically reliable, reproducible, and meaningful Dynamic Handling testing. The tests were also innovative in terms of introducing a bump test to ascertain possible loss of control mechanism leading to rollover. This finding was contrary to claims by some in industry that such testing was not feasible or meaningful.

The Authors are strongly of the opinion that history has clearly demonstrated that advances in safety for all types of land mobile vehicles are correlated with improvements in stability, handling and crashworthiness. Indeed, the Authors agree with the latest September 2014 report and proposed rulemaking (CPSC, 2014) by the US Consumer Product Safety Commission (CPSC) regarding improved handling and stability for SSVs (see Section 2.2.1).

2. DYNAMIC STABILITY AND HANDLING TEST PROGRAM FOR QUAD BIKES AND SSVs

2.1 Introduction

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.

This is the second major test report for the Project, and follows on from the Static Stability test report. The reader is referred to the Part 1: Static Stability Test Results for the detailed introduction and background to the Project, which is not repeated here.

This Report provides the key findings, methodology and analyses from the dynamic stability and handling tests and its significance to the Project and Quad bike and SSV safety.

Attachment 1 of this report provides the detailed test methods and results as presented by Crashlab on the extensive dynamic testing undertaken (over 546 tests).

The Report is structured as follows:

Section 1: Executive Summary

Section 2: Dynamic Stability and Handling Test Program for Quad Bikes and SSVs

Section 3: Dynamic Stability and Handling Overall Rating Index for the 17 Test Vehicles

Section 4: Conclusions

Appendix 1: Copy of US CPSC letter to ROVA dated 28th August 2013

Attachment 1: Crashlab Special Report SR2013/004, Quad Bike Performance Project: Dynamic Vehicle Performance Testing, and Appendices A, B, C, D, E, F.

- **Appendix A – Test specifications**
- **Appendix B – Test matrix**
- **Appendix C – Result summary tables**
- **Appendix D – Instrument response data**
  (Separate attachment as file is very large)
- **Appendix E – Test specimen details**
- **Appendix F – Test photographs**
- **Appendix G – Instrument details**

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=$1000 (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

The sixteen production vehicles and the prototype Quad bike selected for testing are set out in Figure 1 comprising eight Quad bikes typically used in the work place, particularly on farms; three sports/ recreational type Quad bikes; and five Side-by-Side style off-road vehicles used in the workplace/farms. Late in the program, a specially modified prototype Quad bike was provided for testing by Dr. David Renfroe. This vehicle incorporated changes to its track width (around 150mm either side compared to the Honda TRX700XX), an open and lockable rear differential and modified suspension design (independent suspension and tuned shock absorber for spring and damping) aimed at significantly improving stability and dynamic handling. The vehicle is still a prototype and for that reason its identity is not revealed in this report. However, the intention of testing this vehicle was to demonstrate that the rollover resistance and dynamic handling of Quad bikes can be significantly improved for the work environment.

Two Operator Protection Devices (OPDs) were included in the test series to determine their effect on dynamic handling (see Figure 2). Each of the OPDs was fitted to one of the Quad

Quadbar	Lifeguard
QB Industries	Ag TECH industries
8.5kg	14.8kg
	
	

Figure 2: The CPD/ OPD units used in the dynamic tests with the 'work' Quad bike. Top frames: on Tilt Table. Bottom frames: with outrigger wheels.

bikes (Honda TRX250). This Quad bike was selected to represent a typical median result with respect to rollover resistance. The vehicle was also out fitted with outrigger wheels to ensure riders were safe during these tests.

2.2 The Dynamic tests

2.2.1 Introduction

Analysis of the control of any system by a human requires an understanding of the human ability to perceive, process, and react to events encountered by the vehicle as it follows the path desired by the driver or rider. This includes the ability of the system dynamic characteristics to receive a control input and respond in a stable manner and provide feedback to the human controller who can then evaluate the response and make adjustments to maintain a desired path. A block diagram (Figure 3) describing such an operator/vehicle system is shown below (McRuer et al., 1975). The McRuer et al. study set out to determine how the response of a vehicle to a driver's steering input affects the driver's ability to maintain precise control over vehicle path. He stated in his opening paragraph of his report, "*With this knowledge we can identify those vehicle steering response characteristics which may lead to imprecise vehicle path control and which may, in turn, lead to accidents.*"

Since the McRuer et al. 1975 study there have been many attempts made to quantify human control of a vehicle, especially for the purpose of modelling. (Lee et al., 2010; Jurgensohn, 2007; Weir and Di Marco, 1978; Weir et al., 1977; McRuer et al, 1977 and McRuer, 1980, and MacAdam, 2003). As is typical, these studies quote heavily from McRuer but do not change the fundamental parameters or requirements he identified for effective vehicle control. Moreover, they build on his study for the purpose of defining characteristics of a computer model or the functionality of driver assist technology.

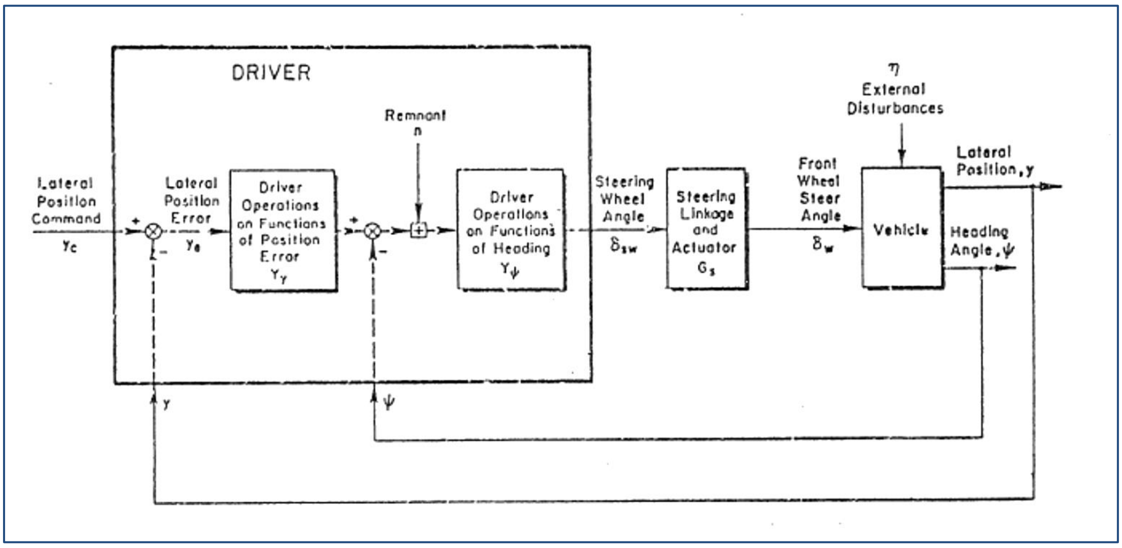

Figure 3: Block Diagram of Driver/Vehicle System for Lateral Steering Control and Regulation (McRuer et al., 1975)

All of the studies referred to above have shown that control of any machine by a human requires that the vehicle responds quickly to a control input. The human controller then recognises the effect of the control input through visual or tactile perceptions, analyses the response and determines any error with respect to the desired effect, then adjusts the control input to correct for any error in the response. There is a finite time in which this can occur, beyond which the operator inputs additional control demands, to speed up the required response. This situation can lead to an exponentially degrading or oscillatory pattern resulting in a loss of control. Control implies the machine must respond the same way to a given control input, respond in a timely manner, and not change the response over time when the inputs are held constant. For dynamic systems such as vehicles, the response time must be short enough to allow the controller to adjust the control inputs to safely manage a vehicle at speed along a desired path. When the vehicle or machine ceases to respond or is random in its response then that vehicle is “out of control.”

Research regarding dissimilar vehicles as a starting point for understanding and improving vehicle control is not a new or novel endeavour. A 1956 study drew on the work concerning the stability of aircraft and ships to understand and improve the handling of road vehicles (Segal, 1956). Milliken et al. (2002) also relied on aircraft studies to improve the handling and longitudinal stability of the modern automobile (Milliken, 2004; Milliken and Milliken, 1995)). Similarly, the automobile/operator interface has been used in the study of the handling of Quad bikes. Indeed, in the SAE Technical Paper "An Introduction to the Operational Characteristics of All-Terrain Vehicles", authors Weir and Zellner (1986) argue:

> *"Handling qualities include, in general, controllability which in turn involves ease of control, the ability to follow a desired path or make the desired manoeuvre, and the ability to suppress disturbance inputs, whether they arise from the environment or from within the system itself."*

The use of internationally accepted tests that determine handling characteristics for road vehicles can, with some assumptions and extensions, be adapted to Quad bikes and SSVs. Simply put, they are four wheeled, powered vehicles being directly controlled by a human operator and the tests apply to any such vehicle, regardless of its specific design or purpose (allowing for differences in vehicles).

A review of National Coroner’s Information System (NCIS) data and a subsequent detailed review of Coroner’s case reports for Quad bike deaths in Australia by McIntosh and Patton (2014) identified rollover as the most significant fatal crash causes. The rollover typically occurred as a loss of control situation where the vehicle was travelling on firm ground, including unsealed roads and dry paddocks, and/ or after striking a bump obstacle. With this in mind, it was decided by the Quad Bike Performance Project team to focus attention on those riding and handling characteristics that can potentially cause loss of control described under these key circumstances.

There are two control characteristics that the Authors consider can be used to determine if a vehicle is controllable; the understeer/oversteer characteristic (Segal, 1956) and the steering response time (McRuer et al., 1975). It is important to note that while subsequent research has refined the specific parameters and requirements of human responses, the fundamentals of vehicle dynamic handling, just like the laws of physics, have not changed since these seminal studies were first published. A vehicle that has poor handling characteristics will be unwieldy and/or will be slow to respond to operator inputs.

Another concern is that the suspension system response to a bump or single obstacle impact can cause the rider to be partially displaced from the saddle, resulting in them falling off (to impact the ground or another hazard) or a rollover crash occurring.

There are distinct relationships between the fundamental control characteristics of vehicles and the occurrence and consequence of certain de-stabilising or excitation events. Vehicles with an excessive understeer or oversteer characteristic are difficult to manoeuvre at low speeds and at higher speeds can require control inputs that are counter-intuitive. In emergency situations this can lead to the compounding of problems, which can result in a loss of control crash.

The industry (through FCAI) claim that there is currently no incident statistical data available or collected to enable determining the correlation (if any) between a vehicle's handling characteristics and collision and injury risk. The Authors strongly disagree with this proposition providing two examples why their opinions (along with other safety stakeholder's opinions) differ from manufacturer's representatives.

The first example is presented in the United States of America (USA) Consumer Product Safety Commission (CPSC) most recent September 2014 report (CPSC, 2014) proposing a Safety Standard for Recreational Off-Highway Vehicles (ROVs)[4], Notice of Proposed Rulemaking, 16 CFR Part 1422. CPSC staff reviewed incidents reported to them involving the Yamaha Rhino model vehicles between January 2003 and May 2013, to address stability and handling issues with the vehicles. Figure 4 is reproduced from that report's Figure 1 showing the number of incidents reported. A repair program was initiated by the CPSC after negotiations with Yamaha in March 2009:

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[4] Recreational Off-Highway Vehicle (ROV) is the USA's term for a Side by Side Vehicle. ATV is the term used in the USA for a Quad bike. Extract from US CPSC (2014):

> "*ROVs are motorized vehicles designed for off-highway use with the following features: four or more pneumatic tires designed for off-highway use; bench or bucket seats for two or more occupants; automotive-type controls for steering, throttle, and braking; and a maximum vehicle speed greater than 30 miles per hour (mph). ROVs are also equipped with rollover protective 4 structures (ROPS), seat belts, and other restraints (such as doors, nets, and shoulder barriers) for the protection of occupants. … ROVs differ significantly from ATVs in vehicle design. ROVs have a steering wheel instead of a handle bar for steering; foot pedals instead of hand levers for throttle and brake control; and bench or bucket seats rather than straddle seating for the occupant(s). Most importantly, ROVs only require steering wheel input from the driver to steer the vehicle, and the motion of the occupants has little or no effect on vehicle control or stability. In contrast, ATVs require riders to steer with their hands and to maneuver their body front to back and side to side to augment the ATV's pitch and lateral stability. … The seats on ATVs are intended to be straddled, unlike the bucket or bench seats on ROVs.*"

"In March 2009, CPSC staff negotiated a repair program on the Yamaha Rhino 450, 660, and 700 model ROVs to address stability and handling issues with the vehicles. CPSC staff investigated more than 50 incidents, including 46 driver and passenger deaths related to the Yamaha Rhino. The manufacturer voluntarily agreed to design changes through a repair program that would increase the vehicle's lateral stability and change the vehicle's handling characteristic from oversteer to understeer. The repair consisted of the following: (1) addition of 50-mm spacers on the vehicle's rear wheels to increase the track width, and (2) the removal of the rear stabilizer bar to effect understeer characteristics."

The CPSC's (2014) *Figure 1* shows the decrease in Rhino-related reported incidents after the repair program were due to handling improvements, "*Specifically, correction of oversteer and improved lateral stability can reduce rollover incidents …..". An extract of the narrative from that report related to the Rhino-related incidents is as follows:*

"CPSC staff also analyzed the 242 Yamaha Rhino-related incidents reported to CPSC and identified 46 incidents in which a Yamaha Rhino vehicle rolled over during a turn on flat or gentle terrain. Staff identified forty-one of the 46 incidents as involving an unrepaired Rhino vehicle. In comparison, staff identified only two of the 46 incidents in which a repaired Rhino vehicle rolled during a turn, and each of these incidents occurred on terrain with a 5 to 10 degree slope. Among these 41 reported incidents, there were no incidents involving repaired Rhinos rolling over on flat terrain during a turn.

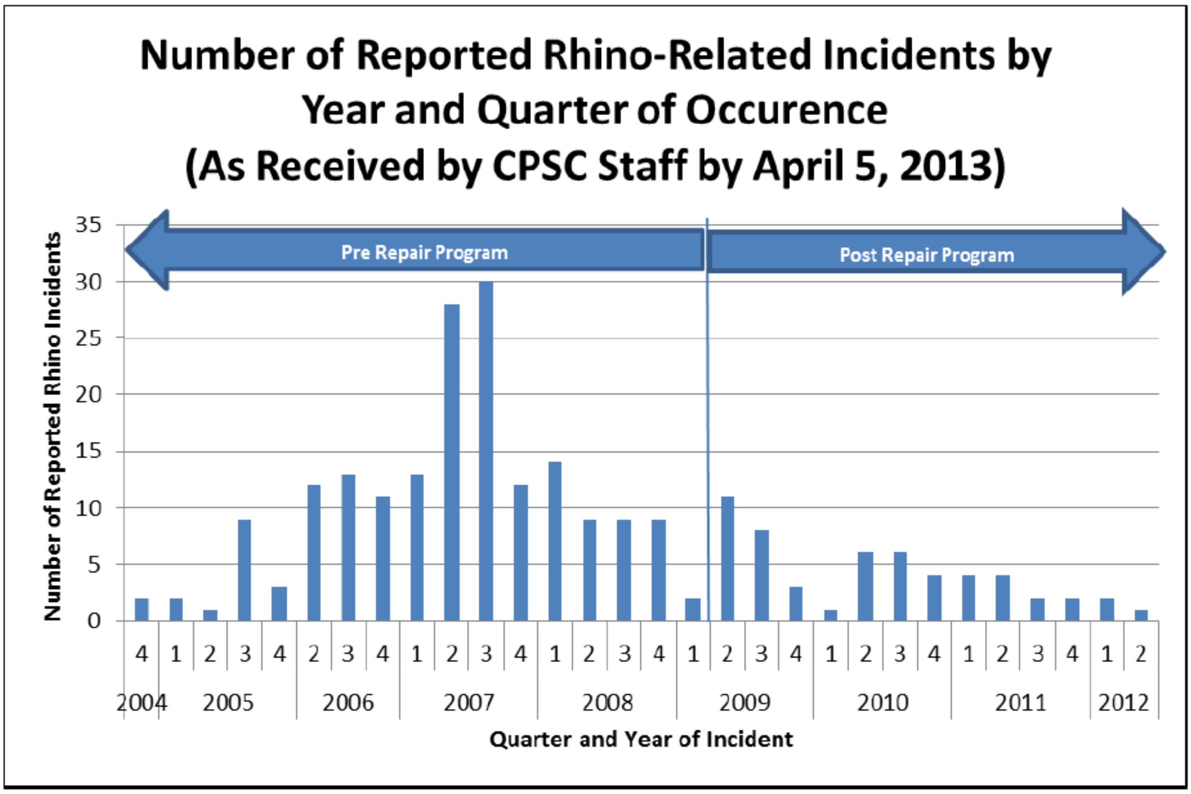

Figure 4: Extracted *Figure 1* from US CPSC's (2014) most recent 'Notice of Proposed Rulemaking' for a 'Safety Standard for Recreational Off-Highway Vehicles (ROVs)' showing the number of reported Yamaha Rhino Incidents from January 2003 to May 2012.

The Commission believes the decrease in Rhino-related incidents after the repair program was initiated can be attributed to the vehicle modifications made by the repair program. Specifically, correction of oversteer and improved lateral stability can reduce rollover incidents by reducing the risk of sudden and unexpected increases in lateral acceleration during a turn, and increasing the amount of force required to roll the vehicle over. CPSC believes that lateral stability and vehicle handling have the most effect on rollovers during a turn on level terrain because the rollover is caused primarily by lateral acceleration generated by friction during the turn. Staff's review of rollover incidents during a turn on level ground indicates that repaired Rhino vehicles are less likely than unrepaired vehicles to roll over. CPSC believes this is further evidence that increasing lateral stability and correcting oversteer to understeer contributed to the decrease in Yamaha Rhino incidents."

In addition the CPSC highlights "*the Commission believes that improving lateral stability (by increasing rollover resistance) and improving vehicle handling (by correcting oversteer to understeer) are the most effective approaches to reducing the occurrence of ROV rollover incidents",* as follows:

"V. Overview of Proposed Requirements

Based on incident data, vehicle testing, and experience with the Yamaha Rhino repair program, the Commission believes that improving lateral stability (by increasing rollover resistance) and improving vehicle handling (by correcting oversteer to understeer) are the most effective approaches to reducing the occurrence of ROV rollover incidents. ROVs with higher lateral stability are less likely to roll over because more lateral force is necessary to cause rollover than an ROV with lower lateral stability. ROVs exhibiting understeer during a turn are less likely to rollover because steering control is stable and the potential for the driver to lose control is low."

The second example relates to the correlations that have been established for Static Stability Factor and risk of a rollover for a diverse range of other vehicle types such passenger cars, SUVs, pickups, four wheel drives and heavy trucks, e.g. Mengert (1989) and DIER 2006. This is discussed in more detail in Section 3.3.2 in the Part 1: Static Stability Test Results and Rating of 17 Quad Bikes and Side By Side Vehicles (SSVs) report. It is obvious from the graphs presented in that Part 1 report (Figures 2 and 3) that the higher the vehicle's lateral stability is, the less likely the vehicle will roll over because more lateral force is necessary to cause rollover than a vehicle with lower lateral stability, i.e. it has a higher resistance to rollover.

The US CPSC (2014) latest report also states:

"The Commission believes that when rollovers do occur, improving occupant protection performance (by increasing seat belt use) will mitigate injury severity. CPSC's analysis of ROV [4] *incidents indicates that 91 percent of fatally ejected victims were not wearing a seat belt at the time of the incident. Increasing seat belt use, in conjunction with better shoulder retention performance, will significantly reduce injuries and deaths associated with an ROV rollover event.*

To address these hazards, the Commission is proposing requirements for:

- *A minimum level of rollover resistance of the ROV when tested using the J-turn test procedure;*
- *A hang tag providing information about the vehicle's rollover resistance on a progressive scale;*
- *Understeer performance of the ROV when tested using the constant radius test procedure;*
- *Limited maximum speed of the ROV when tested with occupied front seat belts unbuckled; and*
- *A minimum level of passive shoulder protection when using a probe test."*

Hence, we the Authors are strongly of the opinion that history has clearly demonstrated that advances in safety for all types of land mobile vehicles are correlated with improvements in stability, handling and crashworthiness. There is no reason why Quad bikes and SSVs should be any different and not obey the same laws of physics and vehicle dynamics.

Thus, it was decided by the Quad Bike Performance Project research team that the understeer/oversteer gradient tests and steering response time (step steer) tests would be conducted generally in accordance with the ISO standard tests.[5] Specific protocols were developed for these tests that take into account the unique characteristics of the Quad bike and SSVs.

Understeer is a measure of a handling characteristic of the vehicle independent of the driver. It can be measured using a circle test as described in SAE J266 (ISO 4138:2012). In simple terms, when the amount of slip angle occurring at the front tyres exceeds that at the rear, then the vehicle is understeering. In these circumstances, more steering input is required to remain on a constant circle path as speed increases. If the amount of slip angle at the rear exceeds that at the front, then the vehicle is oversteering. The driver will have to continually reduce the steering input to remain on the intended path as speed increases. If the amount of slip angle at the front is equal to that at the rear, then the vehicle is said to

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[5] Note that the J-turn test quoted by the in their September 2014 report (CPSC, 2014) is sometimes referred to as the step steer test. It is, in effect, the same procedure as the Lateral Transient Response Test (ISO 7401) that the Authors based their step steer test on. The step steer test was used to determine the Quad bike's and SSV's vehicle response time, measured as the time from the application of a steering input until the vehicle established a constant yaw rate for the desired steer angle, wheel base, and vehicle speed. For the reasons specified later in this report, the Authors decided to use the steady-state circular driving behaviour test based on SAE J266 (ISO 4138:2012) to determine the Quad bike's and SSV's understeer/ oversteer characteristics. Moreover, the decision to use the steady-state circular driving behaviour test instead of the step steer test (J-turn) was made mainly for occupational health and safety reasons, and also (it should be noted) that this decision was made in 2013 well prior to the September 2014 release of the US CPSC's (2014) proposed rulemaking for a Safety Standard for Recreational Off-Highway Vehicles (ROVs). Both test procedures are valid in terms of determining a vehicle's understeer/ oversteer characteristics. Depending on whether the CPSC September 2014 is made law in the USA, the CPSC proposed J-turn Dynamic Handling test procedure could be used for future ATVAP rating procedures.

be neutral steer, which means regardless of speed, the driver would not have to vary the steering input to remain on the intended path.

These variations in steering response as speed changes are represented diagrammatically in Figure 5, where K is the understeer gradient. If K is negative, then the vehicle has an oversteer characteristic.

To measure the characteristic understeer or oversteer, a vehicle is driven on a circle laid out on a flat surface of consistent coefficient of friction while gradually increasing speed. While driving around the circle, the steering angle and lateral acceleration are measured. The plot shown in Figure 6 shows the steering angle versus the lateral acceleration for a typical (well behaving) understeer vehicle.

The focus of the Quad Bike Performance Project is to encourage those dynamic characteristics that provide predictable and forgiving handling characteristics while remaining responsive and highly mobile in a farming and workplace environment. Moreover, in order to provide predictable and forgiving handling characteristics while remaining responsive and highly mobile, a vehicle should be designed to provide a light understeer response of between 1 to 2 degrees per g lateral acceleration. In light off-road vehicles, this understeer characteristic should continue to at least 0.5g lateral acceleration.

In addition, there are other suspension performance requirements required to meet the vehicle mobility demands that must be satisfied and the necessary mechanical compromises for this may require the steering response to transition to neutral or even an oversteer response at greater lateral accelerations. This same safety requirement is also highlighted in a letter from the US CPSC to the Recreational Off-Highway Vehicles Association (ROHVA) of 28 August 2013, which requested the ANSI/ROHVA 1 Standard be revised to include a requirement for an understeer gradient that is positive (light understeer) from lateral accelerations ranging from 0.1 to 0.5g. A copy of the CPSC letter is attached in **Appendix 1**.

Hence on the basis of the above introduction, it was decided that the test program should consist of three different dynamic test series, namely, steady state circular driving behaviour tests, step steer response tests and bump obstacle perturbation tests.[6] The circular tests were to provide information on the vehicle's limit of lateral acceleration and whether it had an understeer, oversteer or neutral steering characteristic, and the point of transition between them, if it transitioned from one characteristic to another. The step steer response tests provided information on the vehicle lateral transient response time. The perturbation bump tests provided information on pitch and yaw response and how much the perturbation disturbs and displaces the rider from their riding position.

[6] For details refer to the Crashlab Special Report SR2013/004, Quad Bike Performance Project: Dynamic Vehicle Performance Testing, **Attachment 1**.

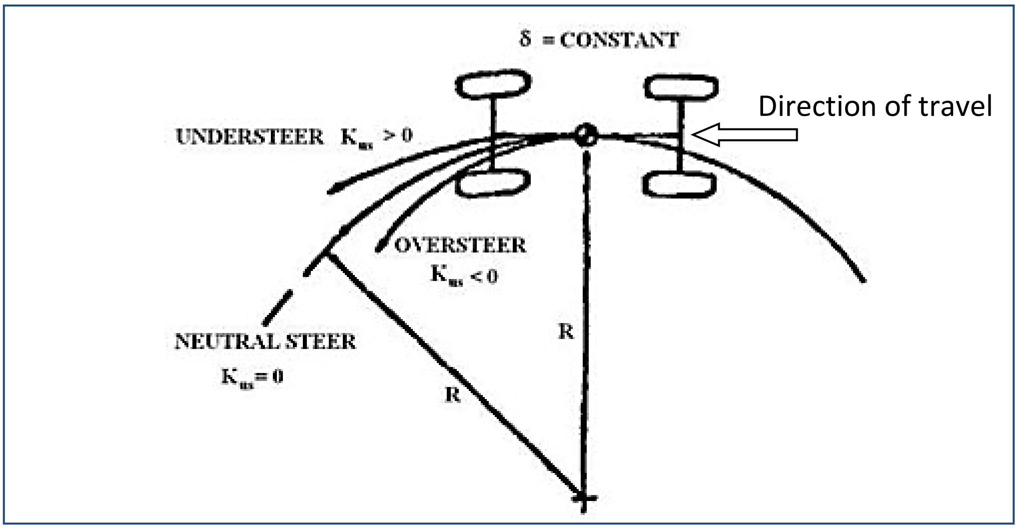

Figure 5: Curve response of neutral, under and oversteer at fixed steer angle

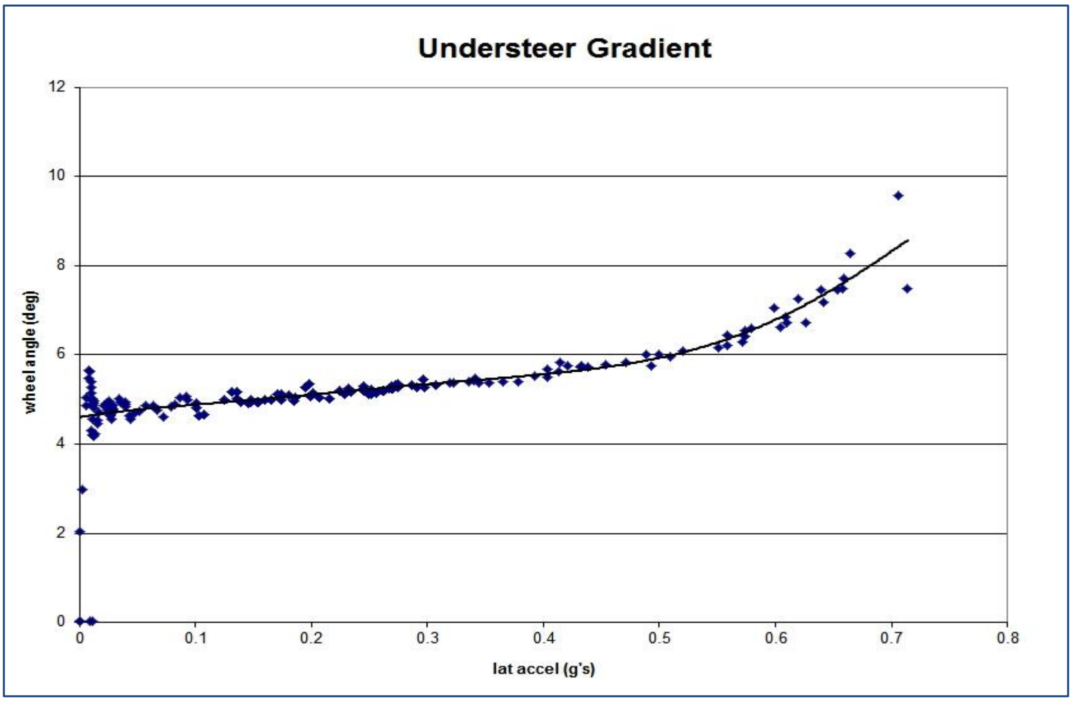

Figure 6: Understeer characteristic for a vehicle with good handling properties.

The steady state circular driving behaviour tests and lateral transient response tests were conducted at Sydney Dragway, Eastern Creek, NSW on both asphalt and grass surfaces. The bump obstacle perturbation tests were conducted on an asphalt surface at Crashlab, Huntingwood, NSW, Australia.

For all vehicles that were tested on the asphalt surface, the surface was flat, smooth and level, with an average coefficient of friction of 0.76. A number of vehicles were also tested on a mowed grass surface at Eastern Creek and on loose bluemetal over compacted roadbase at Crashlab, for comparison of handling response. A number of vehicles were also tested with the maximum recommended cargo load applied to each of the designated cargo areas for the steady state circular driving behaviour tests and lateral transient response tests, for comparison purposes.

The basis of each of these test series and methodology is outlined as follows:

2.2.2 Steady-state circular driving tests

The steady-state circular driving behaviour test consisted of slowly accelerating the vehicle from rest whilst tracking around a circle of 7.6m radius (see Figure 7). The vehicle was accelerated until it lifted the two inside tyres off the ground and tipped up, or could no longer stay on the circle, or the rear of the vehicle slid out which caused the vehicle to point towards the inside of the circle, or could not travel any faster.

As mentioned earlier, the tests used for the Quad bike and SSV handling assessments were developed based on SAE J266 (ISO 4138:2012) tests. The circle radius of 7.6 metres (25 feet) was chosen for several reasons. Firstly, it produced lateral accelerations near the vehicle limit (rollover threshold) at speeds at or below 25 km/h. This was considered important because although outrigger devices were fitted to the vehicle to resist rollover (Figure 2 and Figure 7), a crash at these speeds though considered highly unlikely, would have a low injury risk for the test rider should one occur.

These relatively low test speeds also represent the circumstance of a farmer or worker who is riding while undertaking their primary task (such as herding animals, inspecting fence lines, spraying weeds, etc.) in a neutral non-Active Riding position (worst case scenario). While a wide variety of test speeds and steering inputs are possible, this sample speed is representative of the circumstances for at least a large portion of fatal and serious injury Quad bike crashes that have occurred in the workplace in Australia (McIntosh and Patton, 2014; Lower et al., 2012).

The other main reason is that a radius of 7.6 metres is used by the United States (US) ANSI/ROHVA 1-2011 Standard for Recreational Off-Highway Vehicle testing and would remove the need to have different test tracks for the different test protocols.

Following the prescribed circle, the rider steadily increases the speed and data is recorded continuously for as long as the vehicle remains on the desired circular path within ± 0.2m. The maximum rate of increase of lateral acceleration was approximately to 0.1m/sec^2/sec, making each test about 3 mins duration. While other test methods are available within the ISO protocol, this method could be conducted in a relatively small area, produced the least crash risk for the test rider, and the results were able to be transferred directly to response graphs. Tests were conducted in both left and right hand circle directions and repeated at least 3 times in each direction. The Steady State Circular Driving protocols are provided in Appendix A of the Crashlab Report (Attachment 1).

For the steady state circular driving behaviour tests and lateral transient response tests the vehicles were fitted with an AiM EVO4 data acquisition unit which was mounted close to the vehicle's centre of gravity. This data acquisition system has an internal tri-axial accelerometer and was configured to record external instruments measuring yaw rate, steering angle, vehicle velocity via GPS and vertical distance to ground on the vehicle's left and right side. The acquisition rate was 100Hz. The vehicles were also fitted with an under-body camera to record the point of wheel lift on the steady state circular driving behaviour tests. Hence, for example, lateral acceleration was continuously recorded at 100 Hz along with synchronised video recording such that at the point where both wheels were observed to lift off the ground, the lateral acceleration at that point could be determined. Details concerning the test instrumentation are also presented in the Crashlab Report (Attachment 1).

In terms of the oversteer/understeer response all charts in this project have been standardised so that oversteer is shown as a negative gradient and understeer is represented by a positive gradient. This variation to sign convention was done to make the results easier to interpret. An example plot for the Polaris Sportman 450HO is shown in Figure 8. Each dot on the graph represents a data point taken at 100Hz then filtered during post-processing using a 10 step moving average filter.

The test results shown graphed as red points in Figure 8 were used to determine a line of best fit using a 2nd order polynomial, to determine the understeer/oversteer gradient. The detailed curve fits for understeer/oversteer parameters are shown in Appendix D of the Crashlab Report SR2013/004 for the 240 tests[7]. The results of the steering characteristic testing for every vehicle were very closely grouped, demonstrating good repeatability of the test procedure. In every case but one, the understeer gradients derived from the graphed results of three separate test runs varied by less than 0.5 deg/g, typically 0.25 deg/g or less.

Scatter is caused by the vibrations from the engine and knobby tyres, including the tyre pulsing effect identified by Renfroe (1996). In addition, the 'stab-steer' method required to follow the circle introduces a step like separation of otherwise continuous results. The test team observed that as the rear wheel lifts and breaks traction on the dry bitumen and dry grass surfaces used, the plow effect on such surfaces is suddenly relieved, which demands a steering correction requirement to remain on path. This then causes the lateral acceleration to reduce and the inside wheel to re-engage the ground and repeated oscillation occurs until at higher lateral accelerations, the inside rear wheel is suspended permanently in the air and the Quad settles down to more stable path following.

While Quad bike industry representatives[8] argue that Quad bikes and SSVs are not specifically designed to be operated on paved surfaces (this is a manufacturer 'warned against' behaviour). The fact remains that they are being used on hard surfaces from time to time and loss of control crashes on those hard surfaces are occurring in Australia and

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[7] The 'line of best fit' methodology is detailed in the Crashlab Report SR2013/004, Appendix A (**Attachment 1**).

[8] This includes both manufacturers and distributors of Quad bikes and 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.

Figure 7: Steady state circle testing on asphalt and on grass. Top left: Rider on Quad bike following circle. Top right: Rider on Quad bike following grass circle at point of tilt. 2nd row: Grass circle test site 3rd row: Typical Quad bike circular driving behaviour test (G130449) – both wheels lifted. Bottom: Yamaha Rhino SSV with outrigger wheels.

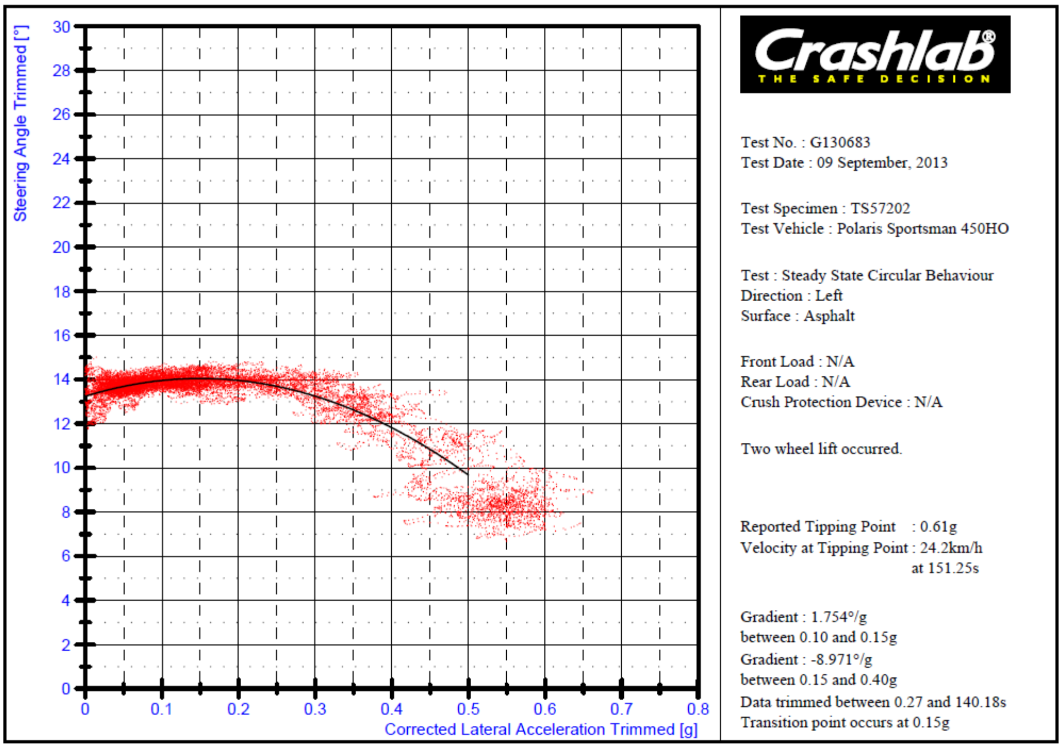


Figure 8: Understeer/oversteer graph for the Polaris Sportsman 450HO showing characteristic understeer (1.754 degrees per g) transitioning at 0.15g to oversteer behaviour of around -8.971 degrees per g between 0.15g and 0.4g lateral acceleration.

elsewhere (including the US (Denning et al., 2013), Canada and Sweden). The project demonstrated that the vehicle characteristics identified by the handling test results are not surface dependent, within certain limits.

Alternate testing was conducted on various surfaces including asphalt, loose bluemetal over compacted roadbase, and on grass. It was acknowledged by the Authors and the test team that there will be a variation in handling response if operating the vehicle on a plastic (i.e., yielding) surface, such as course sand or thick mud, where the surface grip at the tread face is relatively low causing increased slip and early saturation, but sideways movement is opposed by material that will build up against the outside of the tyres, both reducing the amount of slip and increasing rolling resistance. This was not considered to be a critical issue, since on those surfaces a rider will normally adapt their riding style and limit their top speeds to suit the riding circumstances. Firmer and smoother surfaces however, encourage higher speeds, since the rider experiences smooth running and has no expectation of needing to undertake an emergency manoeuvre or critical steering response.

Similarly, there was concern that the test would be rider dependant in terms of mass variation. To address this issue, the vehicle was ballasted to a standard load, described as 'rider only'. The total standard load was the sum of the mass of the rider with his/ her safety clothing and equipment, outriggers and data acquisition equipment, along with any necessary ballast, i.e. a total of 103kgs ± 0.5kgs. This represented the mass of the 95th %ile Anthropomorphic Test Device (ATD) used for the Static Stability testing program.

Additionally, a standardised rider position was established, termed the 'seat reference point' (see Figure 9). This point was defined as when the 95th %ile ATD is fitted to the Quad bike and the hands are fixed to the handgrips. The pelvis was then centred on the saddle and shifted forward or aft until the spine box was vertical (±0.5 deg). A mark was placed on the saddle directly below the vee formed in the skin of the pelvis, below the instrument cavity. This seat reference point allowed the ATD to be quickly returned to the set up position during stability testing and similarly allowed the test riders to quickly adopt a standardised seating position by sitting their own buttocks on the saddle, with their coccyx positioned at the seat reference point.

For most tests, a neutral riding style was adopted, which is to say no 'Active Riding' involving hip or torso shift or standing was undertaken. This was deliberate and represents a worst case scenario, i.e. the situation where a rider who is not concentrating, or is distracted from the riding task for some reason, or is tired after a hard day's work or riding, is suddenly required to make an emergency manoeuvre. The test rider was permitted to lean his upper body into the circle slightly, to counter the lateral acceleration they were subjected to, but was required to generally maintain head, neck and spine alignment.

Standardised rider mass and positioning back to back sample testing with different riders (see Figure 10) on the same machine (Kawasaki KVF300 Quad bike) on the same test

Figure 9: Use of the seat reference position to ensure the rider was sitting in the correct position on the saddle prior to each test run

surfaces were also carried out. Twelve (12) Dynamic Handling tests were used to assess repeatability, i.e. six circular and six step steer tests were repeated with an alternative rider. The results are presented in Tables 2 and 3 of Crashlab Report SR2013/004 (Attachment 1).

Another test series was run to evaluate the effect of different riding positions. This was not a complete assessment of Active Riding style, where the movement of the body at the most appropriate time provides a transient or dynamic benefit to vehicle stability beyond the simple variation to static stability. It was a simplified series of tests to assess the effects of the rider leaning well forward, fully rearward and leaning into the circle as far as possible (Figure 11 and Figure 12).

Figure 10: Different riders undertaking back to back testing. Results obtained (Attachment 1) show the vehicle characteristic is not rider dependant.

Figure 11: (left frame) Rider sitting at the seat reference point; (right frame) body shifted inward, forward and torso leaning into the turn. Rider weight is transferred forward and also to the inside footrest by this movement. Rollover resistance is thus improved by this.

Figure 12: Showing riding position fully forward (left frame) and fully rearward (right frame).

2.2.3 Lateral transient response tests

The lateral transient response test consisted of driving the vehicle in a straight line at a velocity of 20 km/h and then rapidly inputting a steering response to generate a lateral acceleration of 0.4g. The yaw rate to steering response time was recorded during the test. Figure 13 shows the rider approaching the circle (top left frame) and when reaching the line inputs a steering response (top right frame) and continues to ride in a circle at a lateral acceleration of 0.4g (bottom frames).

Vehicle response time is the measure of the time from the application of a steering input until the vehicle establishes a constant yaw rate for that desired steer angle, wheel base, and vehicle speed. Weir and Di Marco (1978), identified the importance of response time as part of proper vehicle steering control.

Figure 13: Showing conduct of Lateral Transient Response (Step Steer) Test

"For proper vehicle control via steering of the wheels, front or rear, there are two steering parameters that affect this control, the steering response time and the steering gain. For automobiles, the two parameters (gain and time constant) used in most of the correlation plots effectively describe the key handling properties…"

A standard test for this response time is the Lateral Transient Response Test (ISO 7401). This test is more often referred to as the step steer or J turn test. The intent is to have a near instantaneous steering change to produce a given steer angle and hold that angle and measure the yaw rate of the vehicle while maintaining its speed. Knowing that the steer control takes a finite amount of time, the response time is measured from when the steer angle is at 50% of the desired step steer angle to the time when the yaw rate reaches 90% of the steady state yaw rate.

Weir and Di Marco (1978) found that there is an upper limit to a steering response time above which control of a vehicle is difficult.

"There is also an upper limit on the effective time constant (Te), beyond which the vehicle's directional response is not rapid enough."

That upper acceptable limit for steering response time for passenger car control in lane regulation and lane change manoeuvers on paved roadways at 50 mph (80 km/h) was found by Weir and Di Marco (1978) to be between 0.25 and 0.30 seconds depending on the vehicle steering gain. The Authors adopted a response time of 0.25 to 0.5 seconds as an appropriate response time for both the Quad bikes and SSV assessments.

The lateral transient response characteristic testing procedure was modelled on ISO 7401:2011; Road Vehicles - Lateral transient response test methods - Open-loop test methods, and has been modified to suit the physical and dynamic characteristics of Quad bikes and SSVs. A copy of the Lateral Transient Response test protocols are provided in Appendix A of the Crashlab Report (Attachment 1).

In this test, the vehicle was driven in a straight line at 20 km/h (±1 km/h) and then a steering input was introduced as rapidly as possible to a preselected value and maintained for several seconds after the vehicle motion variables had attained a steady state. The speed was maintained at a constant 20 km/h (±1 km/h) while turning, which required a small throttle increase as the turn was introduced. Throttle and steering stop devices were used to aid the rider select and maintain the required throttle position and steering input. The target time between 15% and 90% of the steering input was not to exceed 0.15 secs (see Figure 14).

The test speed of 20 km/h was again chosen as it was low enough that had something gone wrong in the test, the rider would not be seriously injured and yet the speed provided sufficient demand on the vehicle steering system to establish what the transient response is. In addition, the test was conducted by maintaining vehicle speed. The test can be conducted with constant throttle, constant speed or dropped throttle. Constant throttle resulted in variable lateral accelerations that made it difficult to determine the vehicle

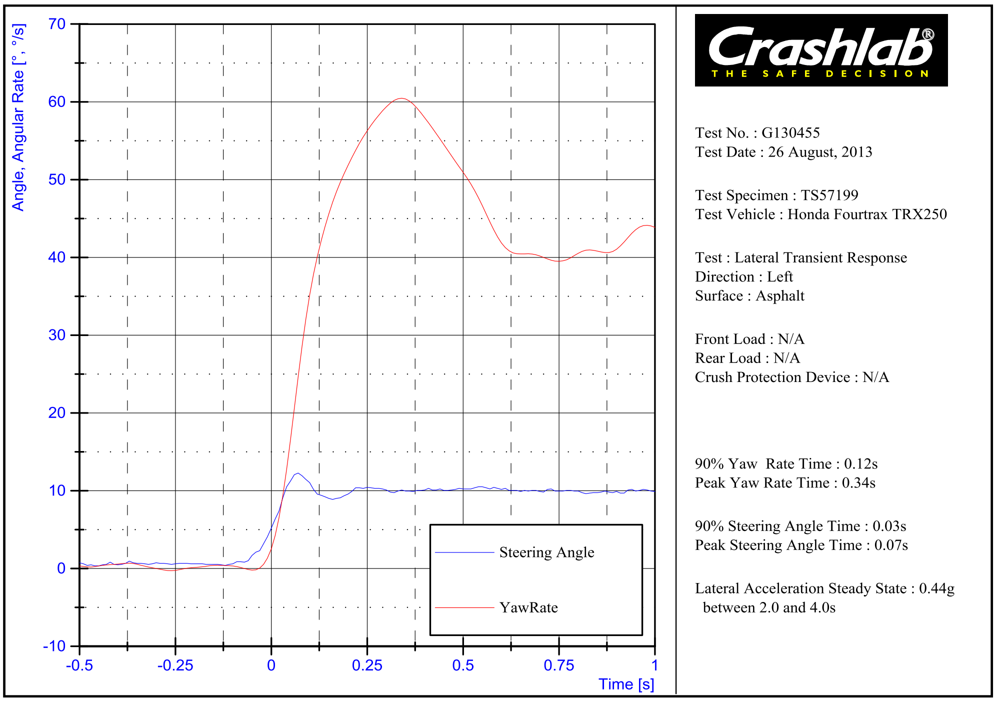


Figure 14: Lateral Transient Response Curve for asphalt testing. This test shows the vehicle had achieved 90% of the steady state steering response for the steering input demanded within 0.12 seconds, which is considered a good response time.

response. Dropped throttle on a vehicle with relatively low mass and high engine retardation made the test invalid, as the vehicle would simply come to a halt with the additional load of cornering.

The Lateral Acceleration demanded of the vehicle (in steady state turning) was 0.4g[9], at the test speed of 20 km/h.

The steering input required to describe a circle to produce this value was calculated using the Lateral Acceleration formula:

$$\boldsymbol{A_y} = \frac{\boldsymbol{v^2}}{\mathbf{9.81} \times \boldsymbol{r}}$$

where: $\boldsymbol{A_y}$ is Lateral Acceleration, in gravities; $\boldsymbol{r}$ is the turn radius in metres; and $\boldsymbol{v}$ is the velocity, in metres per second.

The Ackerman Steering Angle for the desired lateral acceleration can be determined from the formula:

$$Ackerman\ Steering\ Angle = arctan\left(\frac{wheelbase}{radius}\right)$$

Theoretically, the steering input can be pre-set using this equation, where the Ackerman Steering Angle is taken as the average of the steering angles of the left and right wheels.

[9] 0.4g is the lateral acceleration required by ISO 7401:2011; Road Vehicles - Lateral transient response test methods - Open-loop test methods.

The procedure specified in American National Standard ANSI/ROHVA 1- 2011 Section 8.3.4 *Test Procedures*, (with minor modification) can be used to determine the wheel angles required. Because the Quad bikes and SSVs have significant compliance within the steering system and the low pressure tyres and also due to the plow effect caused by the fixed rear axle, it was not possible to achieve the required lateral acceleration at steady state based on a calculated angle. Hence, iterative test measurement was required to establish the appropriate steering angle to achieve the required lateral acceleration at 20 km/h.

Data was noted for the desired steering inputs and response variable outputs and the test was repeated at least three times in each direction.

Similar to the circle testing, the rider was required to keep his buttocks positioned at the ‘seat reference point’ on the saddle throughout the tests and only lean their upper body into the turn, to counter the lateral acceleration being generated. Head and neck were to remain in general alignment with the upper body.

2.2.4 Bump obstacle perturbation tests

The Bump obstacle perturbation test consisted of towing the vehicle in a straight line towards a 150mm high semi-circular ‘bump’ object lined up with either the right or left vehicle track. Each vehicle ‘free-wheeled’ over the obstacle without being under the effect of the tow system. An ATD was positioned on the vehicle with the pelvis acceleration recorded.

As stated previously, the dynamic handling characteristics of a vehicle form a very important part of vehicle’s active safety, especially so for a vehicle that offers little or no crash protection, making crash avoidance ever more important. Pitch and yaw response to a bump is a function of the suspension geometry and spring and shock absorber design. A part of the suspension, or the ride stiffness of the vehicle, includes the properties of the tyre. Due to the low pressure used in Quad bikes and SSVs, the tyre acts like a lightly damped spring. The overall suspension system will have a major effect on the handling of the vehicle when encountering a bump. Figure 15 shows how the tyre deforms when travelling over a perturbation.

Analysis of the National Coroner’s Information System data (McIntosh and Patton, 2014) indicated there were a number of crashes that resulted from a perturbation caused by the rider striking an obstacle. In addition, a bump obstacle test using a matrix of speeds and heights was recommended by the Industry members of the project steering group in their position paper of 1 October 2013 (FCAI, 2013). The Quad Bike Performance Project team decided to investigate this phenomenon in more detail.

Initial testing was conducted using ‘koppers logs’[10] as the obstacle. These were engaged at speeds of 10, 15, 20 and 25 km/h by riders who were trying to remain in a neutral or inert

[10] Koppers logs are a commercially available treated pine log with a nominal diameter of 125 mm.

riding position on the seat (i.e., not Active Riding)[11]. Very early in testing the research team recognised that striking a bump obstacle was a high risk event. Some of the sample Quad bikes did well to attenuate the bump and the rider was able to ride straight over without significant perturbation or crash risk. Some impacts, however, caused a significant vertical and lateral displacement of the rider, so much so that the rider's bottom was displaced sideways to end up more than 50% off the saddle on some occasions (Figure 16).

The sequence of events that followed from this displacement of a seated rider were that being half off the saddle, the rider's body tended to fall on the outboard side, rotating about the rider's buttocks still in contact with the seat. Because the rider's legs were not positioned or prepared to take their body's load and resist this rolling motion, the rider could only pull on the opposite handgrip to try to reposition themselves, or to try to remain in contact with and stay on the Quad bike. This caused the vehicle to be steered away from the side that the rider was already leaning outboard on (see Figure 16).

Figure 15: Negotiating a 100mm bump obstacle at 25 km/h (ballasted to 103 kg load). The low pressure tyre bottoms out, as has the suspension travel, forcing the Quad bike and rider to rise up over the obstacle. This creates vertical and lateral accelerations for the rider that can be measured by the test protocol.

[11] Note that industry based training courses and owner's manuals recommend standing up with the rider's knees flexed while riding the machine over obstacles similar to that shown in Figure 15. By standing, balancing and centering over the vehicle seat can be maintained. Riding over an obstacle while seated on an Active Riding vehicle such as a Quad bike is a warned against behavior by industry; and in that sense, the bump tests in this project serves to verify why it is a warned against behaviour. However, this requirement by industry further demonstrates the vulnerability of particular Quad bikes to such perturbations in terrain becoming unstable and rolling over. Moreover, from a human factors and ergonomics perspective, to require a rider to be continuously vigilant for such obstacles is an unrealistic expectation and unsafe requirement. Rather than designing a vehicle that is human error tolerant, and can traverse terrain with moderate obstacles without requiring Active Riding, the manufactures instead appear to simply accuse the rider of performing warned against behavior and thus absolve themselves of the need to improve vehicle design. Hence, the introduction of such a test to highlight the vehicle's low rider 'warned against behaviour' tolerance.

What is interesting to note is that there appears to be a dominance of left side rollover compared to right side rollover for workplace fatalities (McIntosh and Patton, 2014). It is speculated by the research team that having the thumb throttle on the right handle bar may be resulting in the rider inadvertently over accelerating the Quad bike during a rollover bump event as depicted in Figure 16. That is, when the rider attempts to pull themselves back onto the straddle seat to regain control of the Quad bike, particularly when they use their right hand, they may be inadvertently pressing the thumb accelerator and thus further exacerbating the rollover mechanism.

It was obvious to the Quad Bike Performance Project research team that the consequence of steering away from the side the rider is leaning out meant that either the rider must let go and fall to the ground (with a risk of striking hard and dangerous objects with their head or receiving serious neck injuries) or to hold on, which would in turn cause the Quad bike to roll over, i.e. the rider would effectively pull the vehicle over on top of them. It should be noted again that industry recommends Active Riding when negotiating such obstacles. However, in many terrains such obstacles may not be visible to the rider such that Active Riding is not implemented in time.

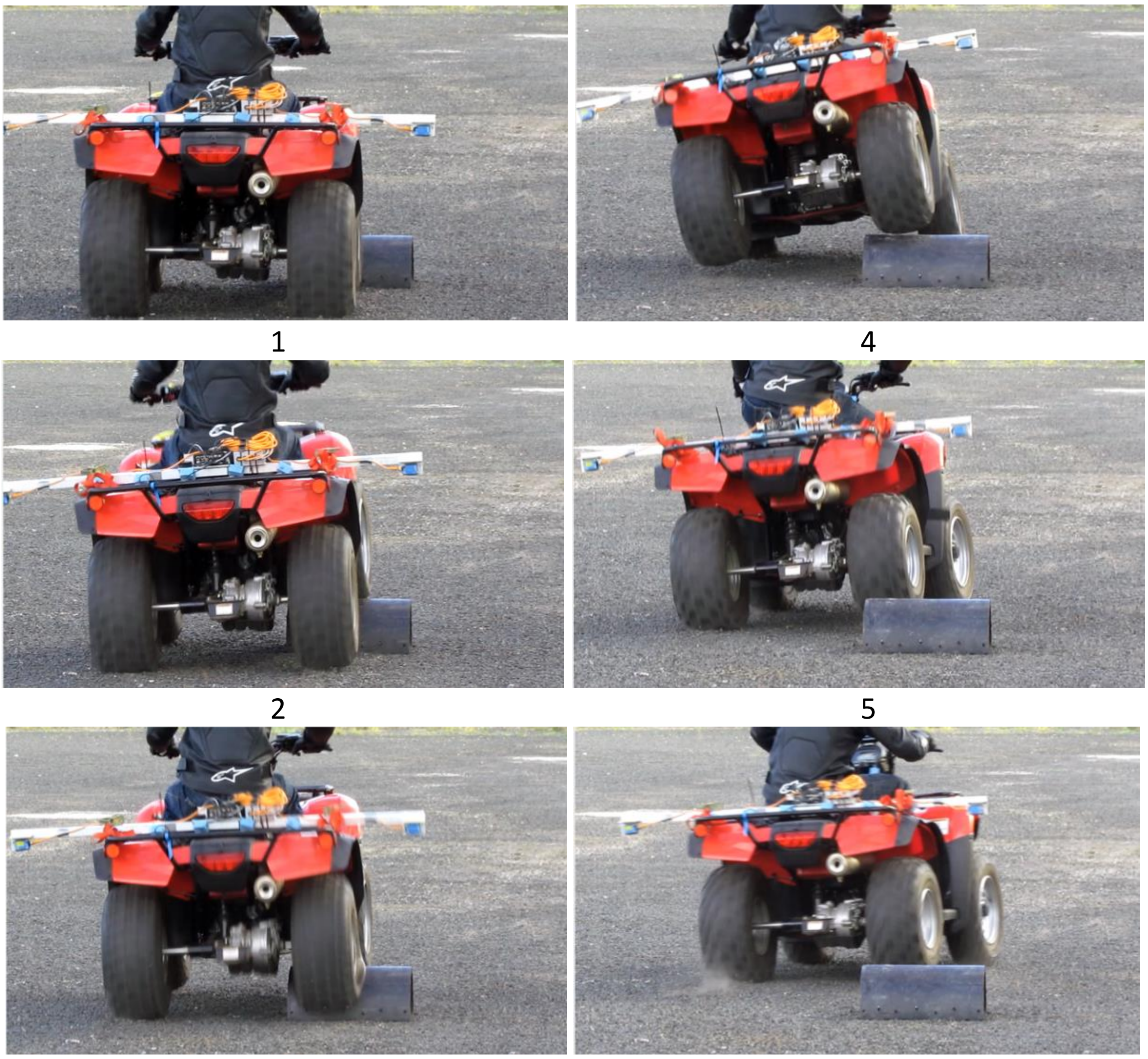
This crash mechanism was considered dangerous and since there was some evidence in the NCIS data that this could be a crash mechanism involved in a number of fatal crashes, it was decided the asymmetric bump obstacle response of each vehicle was an important safety characteristic to include in the Australian Terrain Vehicle Assessment Program.

Acceleration data was measured using accelerometers fitted to the rear cargo tray of the Quad bike, measuring the vertical and lateral accelerations experienced by the vehicle chassis when negotiating the obstacle. Laser height measurements were also used to determine vehicle body roll angle.

During a visit at the early stages of test development by the FCAI representatives on the Project Reference Group, Dr. John Zellner suggested the team try using asymmetric obstacles that were semi-circular, with radii of 100, 150 and 200mm. Suitable obstacles were developed and tested at these same speeds (10-25 km/h). The perturbation experienced by the rider indicated that while the largest obstacle produced the most perturbation, there was sufficient disturbance created by the 150mm obstacle to warrant its use as the test obstacle.

Further justification was found in narratives of Coroner’s reports, where 150mm obstacles were occasionally described (McIntosh and Patton, 2014). The team also considered that 150mm obstacles such as logs, rocks, ruts and grass tussocks were more likely to be concealed by long grass or might not appear to be a threat to the rider, whereas the larger 200mm obstacle would more likely be seen by a rider and because of its size, an appropriate riding style was more likely to be adopted to negotiate it correctly.

Left side perturbation



1 4

2 5

3 6

Right side perturbation

Figure 16: Time series photographs of rider on Honda Fourtrax TRX250 negotiating 200mm bump obstacle at 25 km/h. Note the lateral displacement of the rider and the vehicle yaw.

Data acquisition test runs were made using the 150mm obstacle at the various speeds. The results were difficult to interpret during the early stages of test development and contained a large amount of signal noise, caused by both the knobby tyres of the Quad bikes and the vibrations of the single cylinder engine. In addition, the results were widely scattered, with little repeatability. This methodology proved difficult for several reasons. Video analysis of the seated rider negotiating the obstacle showed that no matter how hard he tried, it was impossible for him to completely relax and strike the bump as if it was entirely unexpected. Variations in arm and wrist stiffness, calf and thigh clench around the cowling, stiffness of leg muscles and hip/knee joints etc., were all highly variable. The data also indicated the response at the cargo rack and failed to include the saddle cushioning as part of the attenuated perturbation of the rider. For these reasons it was decided that an ATD would be a more reliable instrument to measure the likely response of the vehicle and rider to a bump obstacle. While differences in response in such a test between a human and an ATD are likely to exist, nevertheless, observations by the study team of the motion of the ATD and a rider appeared sufficiently similar.

The test team then developed a methodology whereby the 95th %ile ATD would be seated on the Quad bike and the vehicle towed over the obstacle at the test speed, slacking the tow cable just before bump impact. Accelerometers to measure vertical and lateral accelerations experienced by the ATD were installed in the pelvis instrument cavity. Tests were conducted at the various speeds and results analysed.

Based on the results obtained and the knowledge that there was information contained in Coroner's reports suggesting a large percentage of the fatal crashes on farms had occurred at low speeds, i.e. less than 25 km/h, it was decided to use only a single test speed of 25 km/h for the bump obstacle perturbation test (McIntosh and Paton, 2014). Note that selecting a such a single test speed may tend to "tune" the test results to this particular test speed (and bump size), as it is well known that vehicle bump response is highly speed- and vehicle-dependent, and the speed for "maximum response" would be expected to vary from vehicle to vehicle. Nevertheless, as a practical expedient for these tests, one test speed was used for all vehicles tested.

To satisfy the test team that the test did in fact produce an accurate reproduction of the rider experience, a subjective Bump Obstacle Comparative program was also conducted. Each member of the three man research team rode each Quad bike over the 150mm bump obstacle at 25 km/h three times on each side and then assigned that Quad bike's response to the given bump a score between 1 and 10. A score of 1 was considered to be subjectively totally unacceptable or highly hazardous by the individual test rider, whereas 10 was considered very comfortable and of low hazard by the individual rider. The resulting integer scores were summed and averaged and then the Quad bikes ranked in order of best to worst. The results are shown and discussed later in this report.

<u>Splay of Hips.</u> The investigation team considered the issue of the effect the maximum splay of the ATD's hips may have on dynamic handling results, especially the bump obstacle test

results. When setting up the ATD on the Quad bike, it is clear that the larger Quad bikes with wider fuel tank, cowling and saddle cause the ADT's knees and thighs to press firmly against the Quad bike. In effect, the legs are at the limit of their splay. To move the ATD forward on the saddle, the legs must be physically pulled further apart at the knees, then the ATD can be slid forward on the seat. This compares with smaller and narrower Quad bike design, where the ATD may be slid forward and rearward with only minimal effort to splay the knees.

The test team were concerned whether this would affect the results achieved in bump testing. It was considered that it will have some effect, but that the effect would be minimal, so as to be among the noise and variations in measurement. The reason for this is that while moving the ATD forward and rearward does require effort to splay the legs, moving the ATD sideways requires no additional adjustment of the knees or legs. The ATD is free to move vertically and laterally on the saddle in a limited radius without resistance caused by the leg positions. It was recognised that if the lateral displacement was to become very large, then there would be an effect caused by the clenching of the cowling by the ATD legs, but for the displacements observed, the impact on results was considered to be negligible.

Foot Position for Bump Obstacle Test. Negotiation of the bump obstacle causes displacement of the ATD vertically and laterally, varying between each run made with a particular Quad bike. Clearly, whether the foot is in contact with the foot rest at the time of the bump impact and hence will be accelerated upward during the obstacle negotiation, could have an impact on the results. The foot may become displaced from its initial position in which the leading edge of the heel is in contact with the rear edge of the foot peg for a number of reasons. This includes: movement caused during the vehicle's initial acceleration from rest (jerk) toward the obstacle; vibration caused by ground imperfections; vibrations caused by the knobbly tyres on the hard test surface during run-in; and the step onto the boards that the bump obstacle is positioned on for this test series. These all contribute minor variations to final positioning.

This was considered in detail and video analysis of a number of test runs was undertaken to ensure the foot position did not cause results to vary widely or to be invalid. Despite minor movement of the foot occurring during the acceleration and run-in phase of the test run, this did not appear to significantly affect the test results. There was some minor variation in results caused by this phenomena but this was factored into the overall limits of accuracy for acceptable results.

Deformation of Quad bike seat during bump obstacle testing. One variable that was not measured was the individual variation between repeat test runs of the Quad bike seat, caused by repeated application of the bump obstacle forces to the saddle. The saddle itself is generally a plastic base and frame, supported on several rubber mounting blocks along its length and held in position by a locating tongue(s) at the front and a securing latch at the rear. Depending on Quad bike make and model, there is some limited movement laterally and longitudinally of the seat relative to the Quad bike frame, by as much as 10mm. This was generally managed by the testing team, by checking the position of the seat relative to the Quad bike frame as part of the set-up procedure for each test run. The variations were only very minor, but did contribute, along with other variables, to the overall margin of error allowed before results from repeat tests were considered to be within the acceptable accuracy limits.

<u>Effect of initial acceleration from rest of test specimen.</u> During each test run the test specimen was accelerated from a standing start to 25 km/h within a relatively short distance (approximately 30 metres). This entailed harsh acceleration (jerk) at the start, reducing in magnitude as the test speed was approached, such that the tow vehicle was braked just before the moment the front wheel impacted the obstacle, allowing the test vehicle to negotiate the obstacle purely under its own momentum. The investigation team had concerns that the initial acceleration (jerk) that occurs at the start of each test run could affect the ATD set-up position and hence the repeatability of results.

Video analysis was undertaken of several test runs, examining the ATD rearward motion relative to the Quad bike and whether this resulted in the elbows of the ATD pulling straight, so as to be locked in a 'stiff arm' position at the point of impact. This analysis showed that while there was some rearward motion observed during the initial longitudinal acceleration (jerk) from rest, the ATD elbows articulated correctly and repeatedly at the point of impact. This allowed the upper torso to shift sideways as part of the bump induced motions and so as to cause the ATD to then induce a steering effect through the Quad bike handlebar, as the upper arms and forearms articulated relative to each other. It was found that drift in ATD joint stiffness had more effect on repeatability of results than the initial acceleration from rest (jerk) during the test run (for the ATD used for this test battery - one side elbow tightened slightly over time, while one side loosened slightly, requiring regular checking of joint stiffness to ensure consistent results).

<u>Setting the Upper Arm and Elbow Position - Effect on Results.</u> During the initial test development, it was found that some test runs produced highly repeatable results, while others (for seemingly no reason) produced a widely varying visual result (final position of the dummy), despite similar accelerations recorded at the ATD pelvis.

Video analysis of these test runs showed that failure to ensure the ATD elbows were accurately positioned in a slightly bent arrangement, especially if they were locked in a straight arm position, could result in a visibly different outcome after the bump impact. Having the elbow locked straight caused the ATD to push differently on the handlebar and also to resist the torso from falling in the direction away from the bump. This 'stiff arm' of the ATD also appeared to resist lateral movement at the pelvis. The combination of arm articulation, shoulder movement and body displacement resulted in very different visible outcomes, despite the imparted accelerations being similar in magnitude. For this reason the ATD joint stiffness and setup position were constantly monitored during the test series.

A copy of the final Bump Obstacle Perturbation Test protocol is presented in Appendix A of the Crashlab Report (Attachment 1).

Bump Testing SSVs. It was postulated by the Dynamic Handling testing team that the SSVs did not require bump testing. The reasons were that unlike the Quad bike, where the rider sits astride the saddle and any displacing movement is moving the rider towards falling off the side of the bike, the driver of a SSV sits behind the steering wheel and is restrained in their seating position by a seat belt and other lateral restraints (three point seat belt and other lateral restraints if the vehicle complies with the US ANSI/ROHVA 1 Standard).

In addition, the driver has a steering wheel to hold on to and to brace against which, unlike the handlebar of a Quad bike, may not induce a steering input that magnifies the vehicle's bump-induced yaw and roll when pulled on by the driver's upper body lean. Positioning and measuring the reaction of a 95th %ile ATD was found to be difficult and the reactions showed that even if the ATD was subjected to a significant perturbing acceleration, the seat belt and other restraint mechanisms retain the ATD in its position.

It was also considered that the force of the bump for an SSV would probably only be a driver comfort factor, not a safety factor, and that the degree of bump-related comfort can be tested by the consumer by way of a short test drive at the dealership or vehicle display area. Simply driving over a kerb or small log would tell the customer how well the vehicle attenuated the bumps. There was some concern within the Quad Bike Performance Project research team, however, that an SSV may negotiate the bump, but may yaw significantly, possibly enough to go out of control (noting that SSVs are often capable of quite high maximum speeds). To test this concern, the four SSVs tested in this program were driven over the 150mm bump at 25 km/h and the reactions of the vehicle and driver were recorded on video, which was then analysed in detail. The results were as expected, with the driver being restrained and retained in their seating position and no unacceptable perturbation of the vehicle or driver noted

2.2.5 Repeatability Testing

Each test configuration was tested three times to establish result repeatability. Reproducibility testing with alternate riders and on different surfaces (asphalt, grass and bluemetal over compacted roadbase) with and without loads, was also conducted. For detailed results in regards to repeatability testing on asphalt and grass refer to Appendix B and Appendix C of the Crashlab Report (Attachment 1).

2.3 The Dynamic Test Results

2.3.1 Steady-state circular driving behaviour – limit of lateral acceleration

The dynamic test results are summarised in Table 1 and in bar chart form in Figure 17**.** These show for each vehicle the limit of lateral acceleration (in 'g') when two wheel lift occurs (i.e. tip up) or when the rear of vehicle slides out which causes the vehicle to point towards the inside of the circle, i.e. slides out or brakes traction (no tip up). Also shown for comparison is the measured "static" lateral stability in terms of the Tilt Table Ratio (TTR), from Part 1: Static Stability Test Results and Rating 17 Quad bikes and Side by Side Vehicles (SSVs) (Report 1-2013). The observations from these test results are:

1. All the Quad bikes' limit of lateral acceleration occurs by tipping up onto two wheels, which unless able to be counteracted by the rider, is a precursor to rollover or loss of control – that is a loss of stability.
2. For the Quad bikes the measured minimum limit of lateral acceleration at tip up, with rider hips centred, is in the range of 0.36g to 0.55g, and for each Quad bike, was less than its measured TTR (rider only).
3. For the SSVs, these showed higher lateral stability than the Quad bikes, and for the test surfaces driven on and circle radius in a quasi-constant speed steady turning condition, did not tip up except for the Yamaha Rhino.
4. The three Quad bikes that were tested on dry asphalt and dry grass displayed very similar handling characteristics and tipped up at similar lateral acceleration values on both surfaces (see Appendix C in Crashlab Report (Attachment 1)).
5. The Honda TRX250 Quad bike[12] was used as a representative Quad bike for comparing the effects of surface type, load combinations and Active Riding on lateral stability (see Table 2). Further, Table 2 compares the dynamic lateral stability results with those from the static stability Tilt Table Results (TTR). From Table 2:
    a. The representative Quad bike (Honda TRX250)[12] when loaded and tested on dry asphalt, showed a small reduction of less than 6% in lateral acceleration at tip up (0.46g down to 0.43g), and about a 17% reduction when loaded and tested on dry grass (0.46g down to 0.38g).
    b. For the load combinations, the measured limit of dynamic lateral acceleration at tip up was in the range of 0.38g to 0.46g (dry grass and dry asphalt), compared with the static tilt table test of TTR of 0.49g to 0.51g.
    c. With Active Riding (asphalt), the dynamic stability values increased by approximately 13%, from 0.46g up to 0.52g. These values were very similar to the tilt table TTRs (without Active Riding) of 0.51.
6. The example Quad bike (Honda TRX250) when tested with the Quadbar and Lifeguard PPDs, showed only a minor change in limit of lateral acceleration (0.46g down to 0.45g)

[12] A 'representative' Quad was selected for these comparison tests. It was beyond the scope and budget of this dynamic test program to be able to test all of the 17 vehicles in all load and surface combinations. As noted, well in excess of 546 tests were conducted in this dynamic test program alone.

	Type	Make	Model	Min Dyn (g)	TTR (g)	Tip up
1	SSV	Yamaha	Rhino 700	0.61	0.65	Yes
2	SSV	Honda	Big red MUV700	0.56	0.83	No
3	Quad	Polaris	Sportsman 450HO	0.55	0.6	Yes
4	RQD	Honda	TRX700XX	0.55	0.66	Yes
5	SSV	Kubota	RTV500	0.54	0.72	No
6	SSV	John Deere	Gator XUV825i	0.54	0.82	No
7	RQD	Can-am	DS90X	0.54	0.78	Yes
8	Quad	Honda	TRX500FM	0.52	0.58	Yes
9	Quad	CF Moto	CF500	0.50	0.6	Yes
10	SSV	Tomcar	TM2	0.49	0.96	No
11	RQD	Yamaha	YFM250R Raptor	0.47	0.56	Yes
12	Quad	Honda	TRX250	0.46	0.51	Yes
13	Quad	Kawasaki	KVF300	0.46	0.54	Yes
14	Quad	Suzuki	Kingquad 400ASI	0.45	0.57	Yes
15	Quad	Yamaha	YFM450FAP Grizzly	0.41	0.52	Yes
16	Quad	Kymco	MXU300	0.36	0.46	Yes
17	Quad	Prototype	(unlocked differential)	0.56	0.81	No

Table 1: Steady State circular driving test - Average (minimum) limit of lateral acceleration vs TTR (g). 'Yes' is two wheel lift (i.e. tip up), 'No' is no tip up (asphalt surface, rider only).

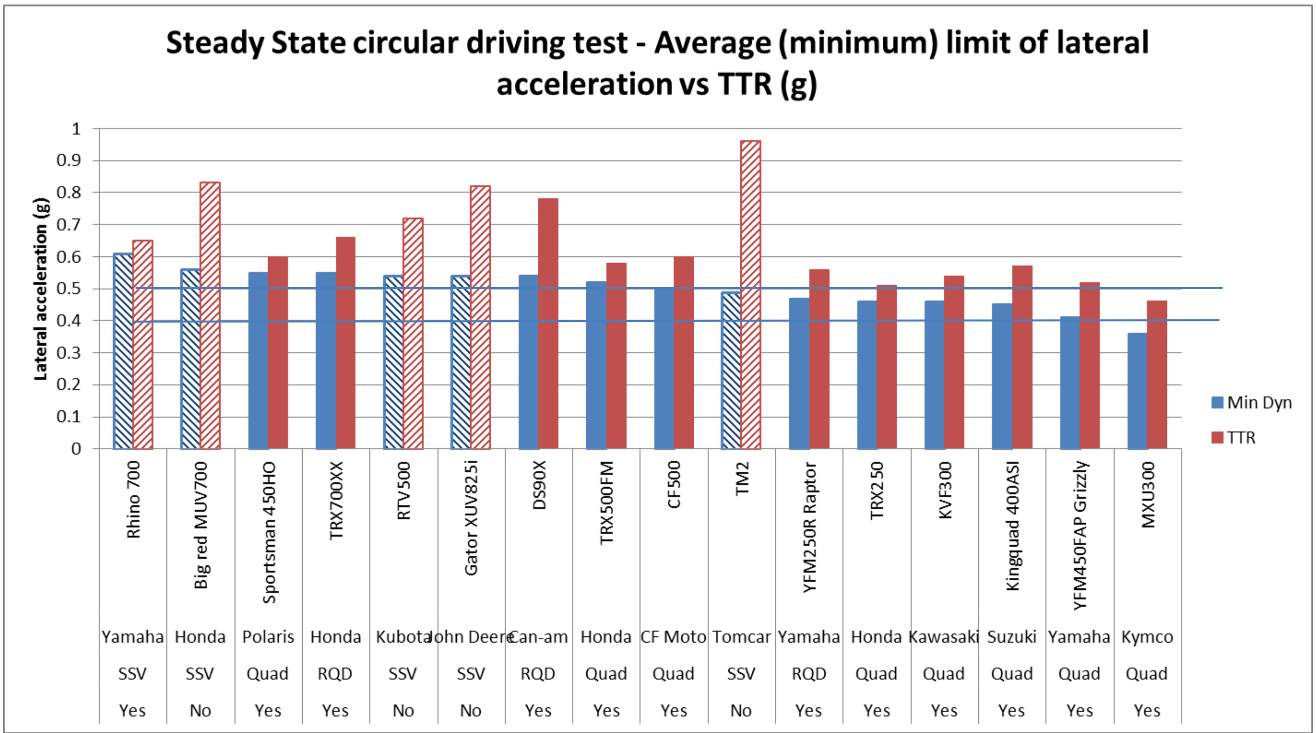


Figure 17: Steady State circular driving test - Average (minimum) limit of lateral acceleration vs TTR (g). The category 'Yes' is for two wheel lift occurring (i.e. tip up), and 'No' is for no tip up (asphalt surface, rider only).

As a comparison, the testing by Scientific Expert Analysis (SEA) for the Consumer Product Safety Commission (CPSC) in the USA of 10 SSVs, reported in detail by Heydinger[13] (2011) (and Heydinger et al., 2011), also identifies that the static rollover metric of Tilt Table Ratio (TTR) provides good correlation with the limit of lateral acceleration (Ay) at tip up for a J-turn test. This comparison[14] of Ay to TTR from the CPSC tests is shown in Figure 18.

			Load Condition				
No.	**Honda TRX250 Quad bike**	**Surface**	**Baseline**	**Operator only**	**Operator plus rear load**	**Operator plus front load**	**Operator & front & rear load**
1	Static Stability Tests (TTR)	Tilt table	0.82	0.51	0.51	0.49	0.49
2	Dynamic Tests-Limit of lateral acceleration	Asphalt	n/a	0.46	0.46	0.43	0.43
3	Dynamic Tests-Limit of lateral acceleration	Grass	n/a	0.41	0.41	0.38	0.40
4	Dynamic Tests-with Active Riding Limit of lateral acceleration	Asphalt	n/a	0.49 to 0.52			

Table 2: Honda TRX250 Quad bike: Effect of surface type, load and Active Riding on lateral stability: Comparison of static stability Tilt Table Results (TTR) with Steady State circular driving test - Average (minimum) limit of lateral acceleration. Static tests used 95th % adult male ATD, with Dynamic test rider similarly weighted.

2.3.2 Steady-state circular driving behaviour – understeer/ oversteer characteristics

The results overall obtained show that most Quad bikes tested for this program have an oversteer characteristic. Table 3 shows the understeer and oversteer and point of transition characteristics for all vehicles. Table 4 shows the understeer and oversteer and point of

[13] It is noted that Heydinger used a 'dropped throttle' J turn test for the Recreational Off Highway Vehicles (ROVs). This produces a slightly different dynamic and because he was testing ROVs with a roll cage and seat belt, he was able to conduct the test at a higher speed. While the test outcomes are somewhat similar, they are different dynamic tests to what this Project conducted.

[14] The graph in Figure 18 is based on the presentation "*Side by Side Off-Road Vehicles, Characteristics, Rollover Metrics and Standards*" given by Lawrence A. Wilson of Wilson Consulting, LLC, Baltimore, wilsonconsulting@verizon.net, at the ANB45(1) Rollover Subcommittee Meeting; Transportation Research Board (TRB), Washington, DC. January, 2014.

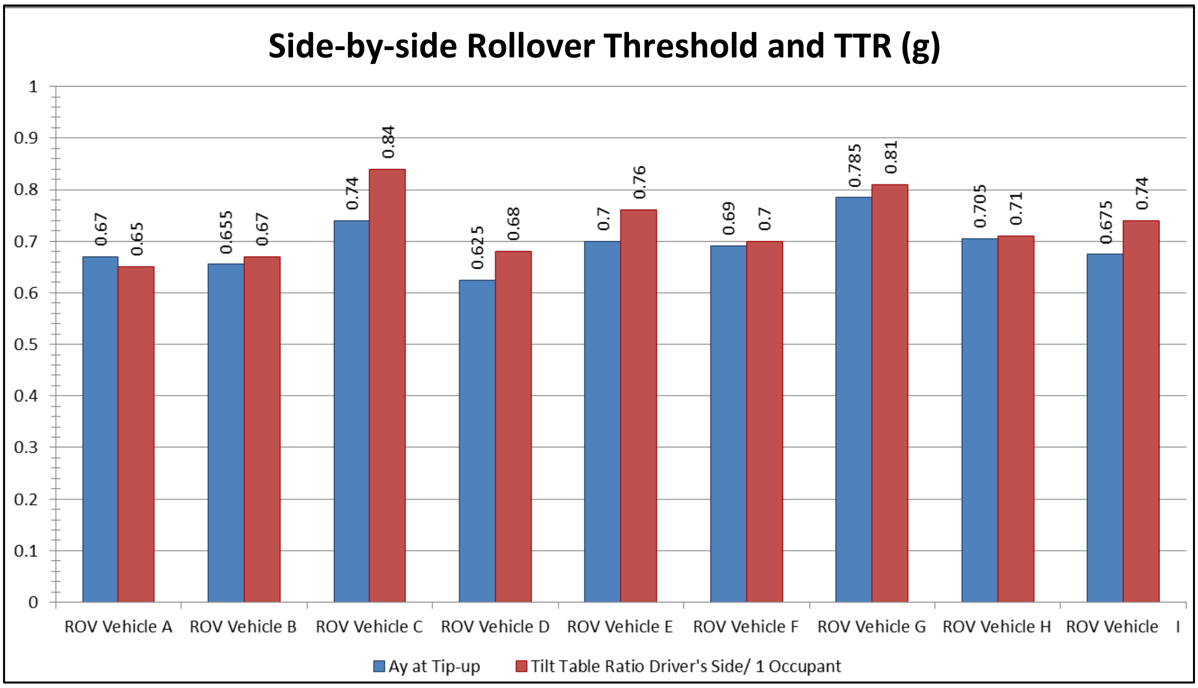


Figure 18: Comparison of Lateral acceleration of SSVs at tip-up (30mph (≈48km/h) J-Turn test) to static rollover resistance metric (TTR) (from Heydinger, 2011)

transition characteristics for different surfaces and loading for selected vehicles. For example, the Honda Fourtrax TRX250 (Figure 19) indicates that vehicle transitions to oversteer almost immediately at 0.01g and subsequently displays around -7.5 degrees per g oversteer characteristic. In contrast, notably, the Honda TRX700 recreational Quad bike (Figure 20), showed a light understeer characteristic of between 2 and 3 degrees per g transiting to a slight oversteer at around 0.3g to 0.35g which is maintained through to beyond 0.5g. This is considered a very good steering characteristic[15] and demonstrates that it is quite possible to design the steering and suspension systems of a Quad bike to produce the recommended handling characteristics desirable for a workplace environment. Importantly, both test riders commented that this vehicle was the most fun to ride as it improved rider confidence and provided very good feedback.

SSVs that have open rear differentials (Honda Big Red MUV, John Deere Gator XUV825 and the Kubota RTV500) all exhibited light understeer handling characteristics. For off-road (e.g., low friction, rough and/or uphill) operations, it is essential that the differential be lockable, to provide traction and acceptable handling on such surfaces. When the rear differential was locked on test surfaces, the vehicle demonstrated oversteer characteristics.

In addition, the open rear differential provided a self-limiting mechanism under the test conditions (7.6m radius), whereby the vehicle could not reach the speed and hence lateral

[15] While there are disagreements in regards to what is considered to be good handling characteristics for Quad bikes overall, the Authors' perspective relates to Quad bike use in the workplace environment.

				Understeer (g) Turning Left		Understeer (g) Turning Right	
	Type	Make	Model	Transition (g)	Gradient (deg/g)	Transition (g)	Gradient Deg/g)
1	SSV	Yamaha	Rhino 700	0.2	-2.92	0.05	-10.58
2	SSV	Honda	Big red MUV700	n/a	2.92	n/a	3.58
3	Quad	Polaris	Sportsman 450HO	0.13	-7.83	0.1	-9.0
4	RQD	Honda	TRX700XX	0.52	2.58	0.51	1.58
5	SSV	Kubota	RTV500	0.35	0.92	n/a	2.58
6	SSV	John Deere	Gator XUV825i	n/a	2.08	n/a	7.92
7	RQD	Can-am	DS90X	0.2	-2.33	0.04	-3.25
8	Quad	Honda	TRX500FM	0.05	-4.17	0.09	-8.0
9	Quad	CF Moto	CF500	0.1	-4.58	0.1	-9.0
10	SSV	Tomcar	TM2	n/a	3.58	n/a	7.0
11	RQD	Yamaha	YFM250R Raptor	0.02	-8.42	0.03	-8.67
12	Quad	Honda	TRX250	0.07	-12.17	0.07	-11.0
13	Quad	Kawasaki	KVF300	0.3	-10.5	0.025	-7.5
14	Quad	Suzuki	Kingquad 400ASI	0.03	-11.08	0.05	-11.33
15	Quad	Yamaha	YFM450FAP Grizzly	0.13	-7.08	0.15	-8.58
16	Quad	Kymco	MXU300	0.135	-9.33	0.1	-11.83
17	SSV	Honda	Big red MUV700 (locked differential)	0.2	-0.83	0.1	-1.33
18	Quad	Prototype	(unlocked differential)	n/a	7.81	n/a	7.54

Table 3: Steady State circular driving test - understeer characteristics and point of transition for the 17 test vehicles. Asphalt surface, rider only. Note that negative understeer is an oversteer characteristic. n/a means the gradient did not transition between under and oversteer in the range tested, i.e. remained understeer.

Steady-state circular driving behaviour – understeer characteristics					
		Operator only Load		Operator plus load	
		Understeer		Understeer	
Vehicle	**Surface**	**Transition**	**Gradient**	**Transition**	**Gradient**
Honda TRX250 (Quad)	Asphalt	0.075	-10.17	0.09	-16.58
	Grass	0.06	-10.33	0.05	-12.57
Honda Big Red MUV700 (SSV)	Asphalt	n/a	3.58	n/a	1.17
	Grass	n/a	4.08	n/a	4.08
Yamaha Rhino 700 (SSV)	Asphalt	0.05	-10.58	0.06	-10.33
	Grass	0.05	-14.42	0.05	-10.92

Table 4: Steady-state circular driving behaviour – understeer characteristics - affect of loading and surface (asphalt and grass). Note: a negative understeer gradient indicates an oversteer characteristic. Honda TRX250 front load = 15kg; rear load = 30kg; Honda MUV rear load = 454kg; Yamaha Rhino 700 (SSV) rear load = 181kg. N/A means the gradient did not transition between under and oversteer in the range tested, i.e. remained understeer.

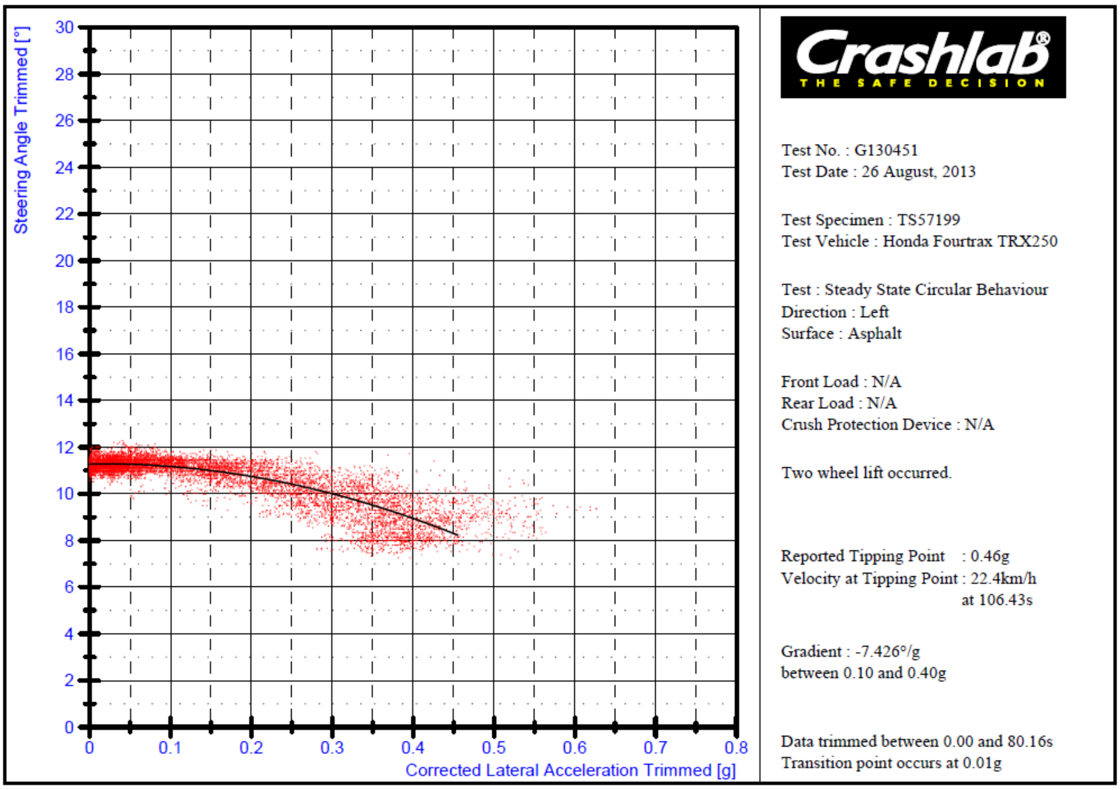


Figure 19: Understeer/oversteer graph for the Honda TRX250 showing characteristic oversteer behaviour of around -7.5 degrees per g between 0.1 and 0.4g lateral acceleration.

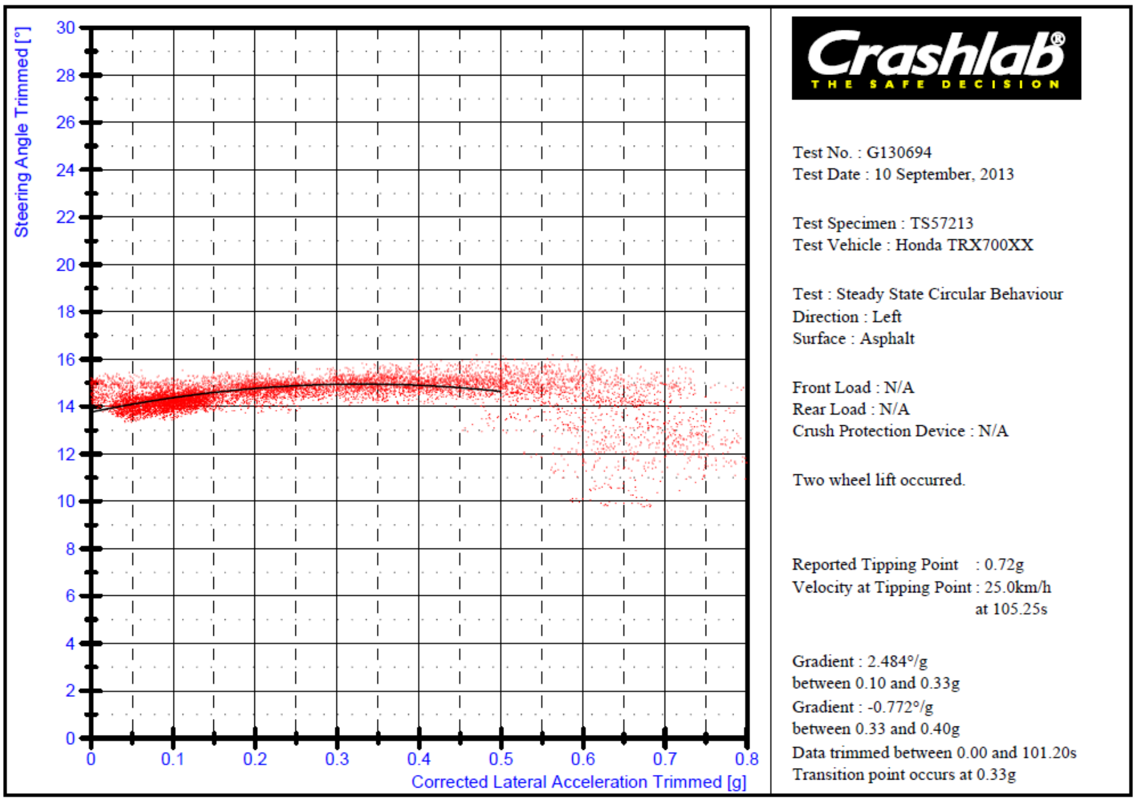


Figure 20: Understeer/oversteer graph for the Honda TRX700XX showing characteristic understeer behaviour of around 2.5 degrees per g between 0.1 and 0.33g lateral acceleration and then transition at around 0.33g to slight oversteer beyond 0.5g.

acceleration required for 2 wheel lift and tip-over. As the inside wheel lifted, drive would transfer to the free wheel and it would spin up, causing a slight loss of vehicle speed and then the wheel would return to the ground. Future testing should consider the use of a larger radius circle so that the vehicle tip up speed could be reached

To make the comparison, the rear differential was locked on selected vehicles and driven on the test circle (Figure 21 and Figure 22). Not only was it more difficult to control the vehicle

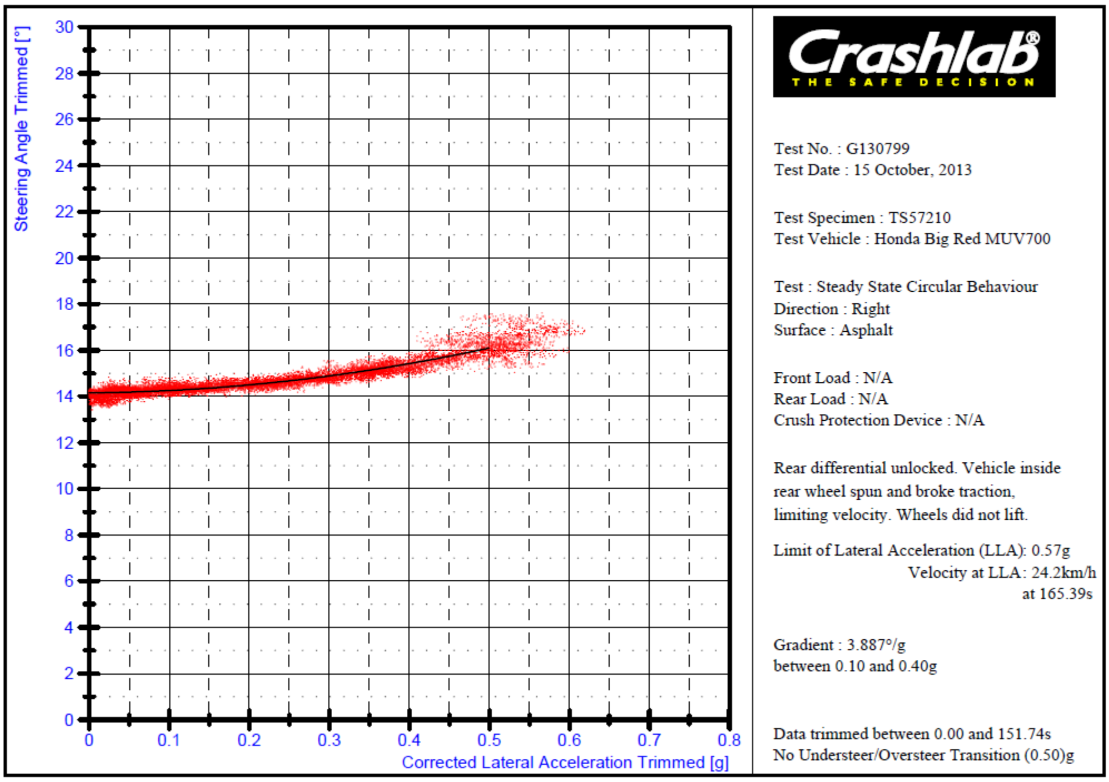
Figure 21: Honda Big Red MUV with open differential on left. Vehicle follows path of test circle easily and top speed is limited by inside rear wheel lift (spin-up). With locked differential on right, MUV oversteered throughout the test, ending up turning into the test circle, sliding sideways to the intended direction of travel and nearly tipped up onto the outrigger wheel.

on the circle, the vehicle reached the lateral acceleration required for 2 wheel lift and the rear slid out, resulting in the vehicle oversteering sharply towards the centre of the circle and a sudden transient roll onto the outrigger wheel at the end of each test.

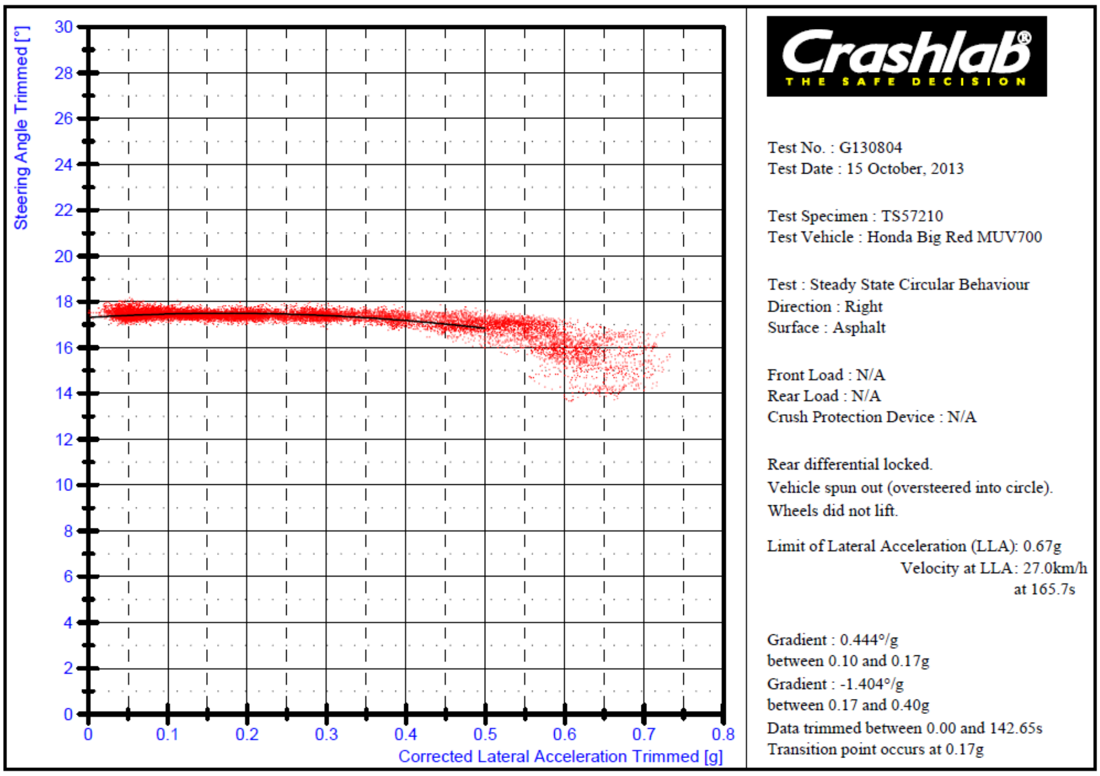
Based on the experiences of the test team, as well as supported by test data, the best handling vehicles had a light understeer characteristic in the range between 0.1 and 0.5g lateral acceleration and also had an open rear differential. This allowed the vehicle to turn freely and not resist the rider or driver due to the plow effect of a locked rear axle. The vehicle were not only more nimble and responsive, it is more pleasant to operate. As previously noted, on some loose low friction surfaces or muddy conditions, the ability to lock the differential is a necessary feature, i.e. differentials should be selectable for both open or locked.

2.3.3 Lateral transient response time

Eleven Quad bikes, the prototype Quad bike and the five SSVs were subjected to lateral transient response tests in a total of forty different configurations. The key finding of the lateral transient response testing was that most of the Quad bikes tested have what can be considered good steering response times (of the order of 0.2 seconds or less), which is to be expected of a relatively short wheel-based, lightweight vehicle that has quite grippy tyres.



Unlocked rear differential



Locked rear differential

Figure 22: Understeer/oversteer graph for the Honda Big Red MUV700 SSV. Top frame: understeer with unlocked rear differential. Bottom frame: oversteer with lock rear differential.

The SSVs also exhibited good steering response times, typically of 0.3 seconds or less at the test lateral acceleration of 0.4g developed at the test speed of 20 km/h, indicating they are generally suitable for use in a farming environment (see Figure 23). Other research (Renfroe, 1996, Heydinger, 2011) has shown higher speeds can produce longer steering response times for SSVs.

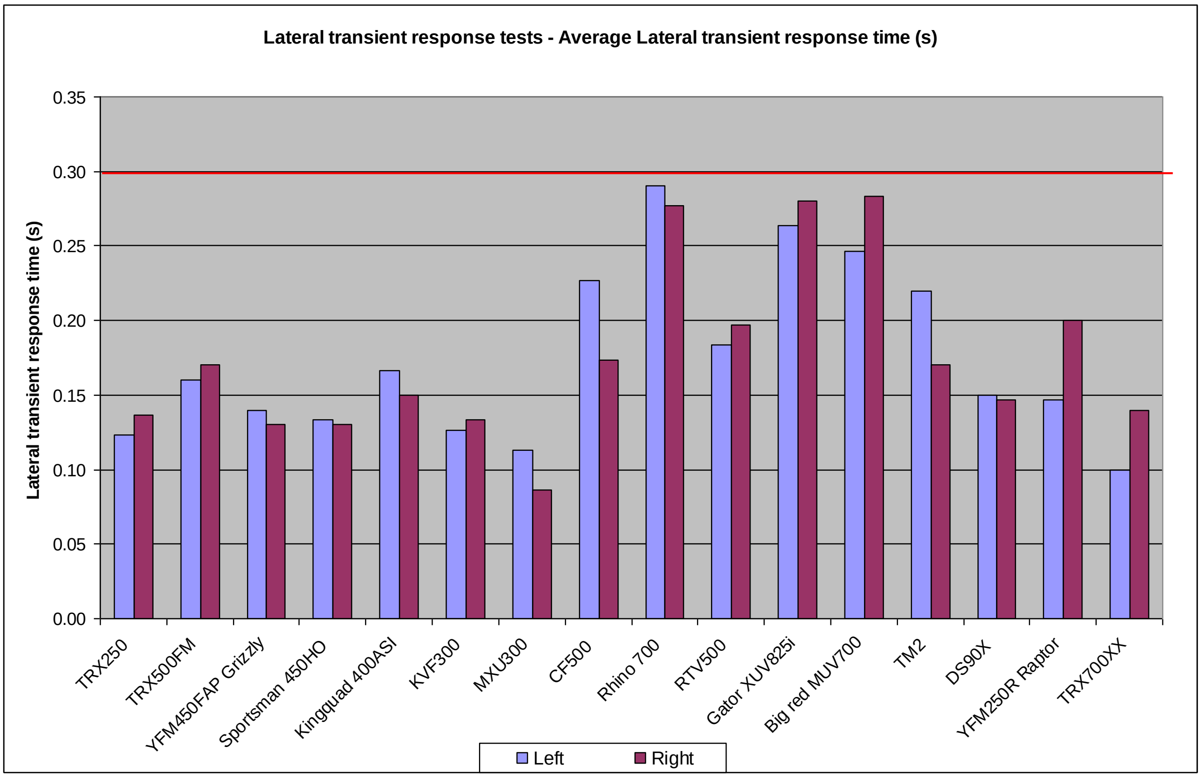


Figure 23: Results Lateral transient response test, average steering response time - unladen vehicles on asphalt (from Crashlab Report – Attachment 1)

The three Quad bikes and two SSVs that were tested on asphalt and grass all displayed slower lateral transient response times when tested on grass. The lateral transient response times were typically in the order of twice as long when tested on grass compared to asphalt. The average lateral transient response times on grass for these five vehicles were less than 0.5 seconds. However, the slowest individual lateral transient response time for one of the SSVs was 0.61 seconds.

In summary, as already noted previously, based on the testing program results as well as the subjective assessments by the test team, the vehicles that handled well (consistently and safely)[16] and were likely to reduce the risk of a loss of control crash occurring, had a slight understeer characteristic when excited between 0.1 and 0.5g lateral acceleration and a lateral transient steering response of less than 0.25 - 0.3 seconds when tested on asphalt.

[16] This is in relation to the typical workplace environment. Of course there are other circumstances such as in some recreational riding or racing where different characteristics are desired.

2.3.4 Test results - bump obstacle test

Eleven production Quad bikes and a prototype Quad bike were subjected to the bump obstacle test. The visible outcomes of the bump obstacle test ranged from the Quad bike with its dummy rider passing straight over the bump, without significant perturbation to either, to a large vertical and lateral displacement of the Quad bike and dummy with associated steering input leading to near rollover of the test vehicle. In between these two extremes, there appeared to be variations that included significant vertical displacement without much lateral displacement and some which included sideways motion (yaw) of the Quad bike (movement of the rear end away from the obstacle). The visible outcome (dummy body roll and steering input) occurred after the accelerations had been imparted by the bump obstacle.

These 'bump tests' identified, possibly for the first time, a significant mechanism in which Quad bike riders may lose control when one track goes over moderately high rounded bumps (similar to half-buried logs, drainage or irrigation pipes, small mounds, rocks, rabbit holes, etc.) with either the left wheels or the right wheels. When the rider and Quad bike is displaced substantially laterally whilst traversing a 'bump', the rider can pull on the handle bar, further increasing the turn of the Quad bike, potentially leading to rollover. In some cases the rider could inadvertently press the thumb accelerator and accelerate the vehicle during this mechanism.

The Quad bikes exhibited ATD pelvis lateral/vertical resultant acceleration values of between 1.47g and 3.66g (see Figure 24). Quad bikes such as the CF Moto CF500 that exhibited lower resultant ATD pelvis acceleration typically negotiated the bump with little lateral movement of the Quad bike and ATD relative to the seat of the Quad bike. Quad bikes that exhibited higher resultant ATD pelvis acceleration typically showed significant ATD movement relative to the seat of the Quad bike such as, for example, the Honda Fourtrax TRX250 (Figure 16).

In regards to the bump obstacle subjective comparative testing, the results are shown in Table 5. This final test configuration proved useful, with the peak resultant of lateral and vertical accelerations being repeatable (within 5% of the arithmetic mean). The experience of test riders with each vehicle generally compared very closely as shown subsequently in Figure 24 to the both the visual assessment of the response of the ATD and the accelerations recorded at the ATD pelvis. The final ranking by the test team was similar to the result obtained using the test protocol, with 9 of the 11 Quad bikes exactly in order and the last two juxtaposed. The two dissenting results had very close riding assessment scores and recorded test accelerations. It is possible the shape of the saddle may have influenced the riding assessment slightly, but the size of the measured differences meant it would be very hard for any rider to discriminate between the performances of these two vehicles.

All of the SSVs traversed the bump satisfactorily, with low level of rider or vehicle perturbation. Subjectively, the best attenuation of the bump was made by the Yamaha Rhino (Figure 25), which hardly disturbed the driver or the vehicle at all. Both the John

Deere Gator (Figure 26) and the Honda Big Red MUV (Figure 27) handled the bump well, with only minor perturbation experienced by the driver and very little course deviation. The largest perturbation observed was the Kubota RTV 500 (Figure 28 and Figure 29), which passed a significant bump on to the driver and displayed noticeable (but not dangerous)

Bump Obstacle Comparative Testing

Vehicle	Test Serial Number	Rider 1	Rider 2	Rider 3	Average	Ranking by Rider - worst to best	Ranking - Peak Resultant Acceleration	Peak Acceleration
Honda FourTrax TRX 250	TS57199	3	3.5	4	3.5	4	4	2.73
Honda Foreman TRX500FM	TS57200	6	4	5.5	5.2	8	7	2.21
Yamaha Grizzly YFM450FAP	TS57201	7	7	7.5	7.2	10	10	1.92
Polaris Sportsman 450HO	TS57202	7.5	6	6.5	6.7	9	9	1.93
Suzuki KingQuad 400ASI	TS57203	5	4.5	4	4.5	6	6	2.25
Kawasaki KVF300	TS57204	3	3.5	4	3.5	3	3	2.97
Kymco MXU300	TS57205	3.5	4	4	3.8	5	5	2.28
CF Moto CF500	TS57206	8.5	8	8.5	8.3	11	11	1.8
Yamaha Raptor	TS57212	1.5	1	3	1.8	2	2	3.15
Can Am DS90X	TS57211	1	2	2	1.7	1	1	3.48
Honda TRX700XX	TS57213	5	4	5	4.7	7	8	2.05

Evaluation of response using 150mm bump obstacle at 25 km/hr

Rider 1	Drew Sherry
Rider 2	David Hicks
Rider 3	Keith Simmons

Table 5: Bump Obstacle Comparative testing with three different riders.

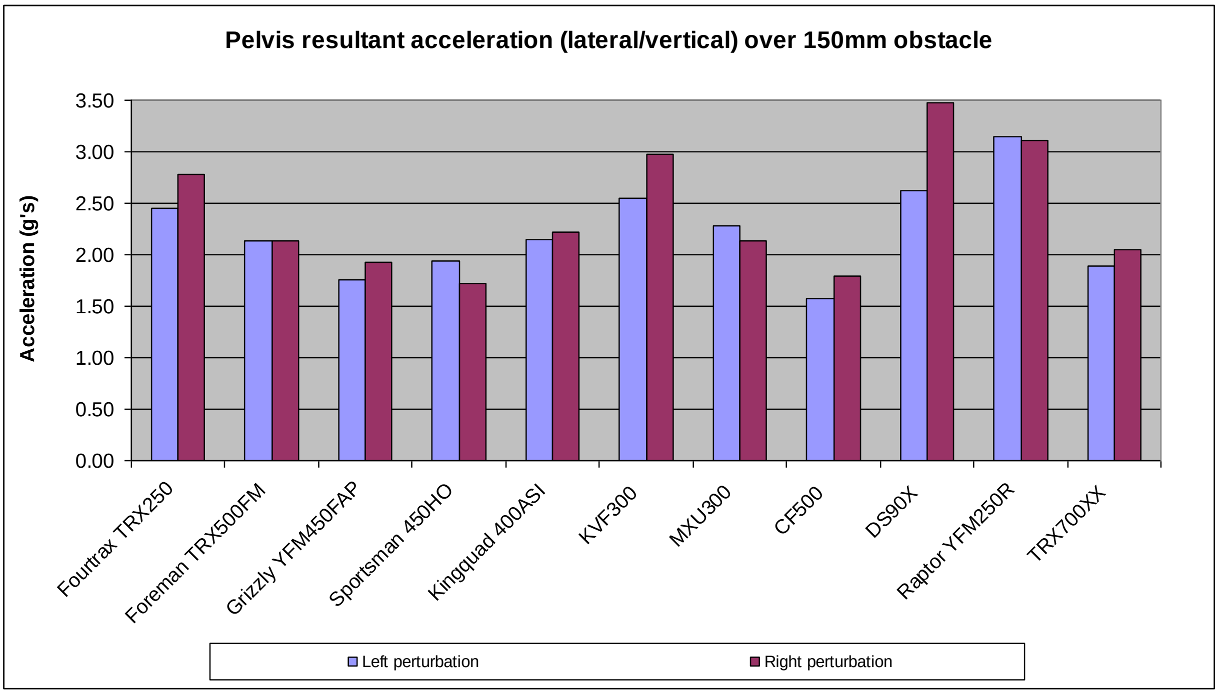


Figure 24: Bump obstacle test results for the 11 Quad bikes.

Figure 25: Yamaha Rhino passes over bump at 25 km/h with minimal disturbance to driver or vehicle.

Figure 26: John Deere Gator passes over bump at 25 km/h with only slight vertical disturbance to driver or vehicle.

Figure 27: Honda Big Red MUV passes over bump at 25 km/h with only slight vertical disturbance to driver or vehicle.

Figure 28: Kubota RTV 500 passes over bump at 25 km/h with minor visible vertical and lateral disturbance to vehicle and driver who holds on to the steering wheel.

Figure 29: Vehicle ended up facing toward the camera, approximately 6 degrees of yaw.

yaw towards the bump (the rear moved away from the side the bump struck). This was not considered as an adverse result because the Kubota's bump response was subjectively considered by the team to be uncomfortable but not unsafe.

2.3.5 Repeatability of results

Each test configuration was tested three times to establish result repeatability. Full results tables are contained in Attachment 1 – the Crashlab report, Appendix B and Appendix C. Table 2 and Table 4 provide summary details of the comparison between asphalt and grass. The results were considered acceptable for all three test series (circle test, lateral transient response and perturbation bump test).

For the Steady-state circular driving behaviour tests, the dynamic vehicle response gave very similar results for each of the three tests for all configurations tested. The results for the circle tests on asphalt were within 10% and for grass it was within 20% variation.

For lateral transient response, the only significant variation between the results obtained on bitumen and on grass are that there are slightly more oscillations occurring in the lateral yaw rate data, due to minor inconsistencies (tufting) in the grass surface. There was a slight increase in response time associated with lower friction coefficient surfaces, as was expected. The lateral transient steering response times for vehicles in the unladen test condition when tested on asphalt varied between repeat tests by less than 0.14 seconds with a significant number of tests displaying a variance of less than 0.05 seconds.

Different riders and different surfaces produced very similar response curves, indicating acceptable repeatability and reproducibility of the test. Figure 30 shows the differences between the two riders used for testing (Figure 10) in regards to assessing understeer/ oversteer response. The top graph has slightly greater data spread, caused by slightly more stab steer as the rear wheel lifted. The second rider was less familiar with this vehicle. Importantly, the characteristic curves have the same shape and represent an oversteer characteristic of around 9.1 to 9.7 degrees/g between 0.1 and 0.4g lateral acceleration.

Concerning the tests on different surfaces, it was anticipated that when the surfaces have reasonable cohesiveness, then the results would be similar in nature (i.e. the characteristic would be the same). The understeer/oversteer response results obtained from testing showed that the only effect the surface type has is to shift the curve up or down on the graph, but does not affect the slope of the curve to any large amount, which is the important parameter describing the vehicle's handling characteristic.

In the Bump obstacle perturbation tests, the lateral/vertical ATD pelvis resultant acceleration values varied by up to 0.45g between three tests of the same vehicle. Typically the variation between repeat runs was less than 0.25g.

These results show good repeatability and confirm that Quad bikes (and SSVs) can be reliably tested and rated for handling characteristics and thus also improvements in handling can be demonstrated, and as a result a rating system such as ATVAP that includes Dynamic Handling can be successfully developed.

2.3.6 Different riding positions (simplified Active Riding)

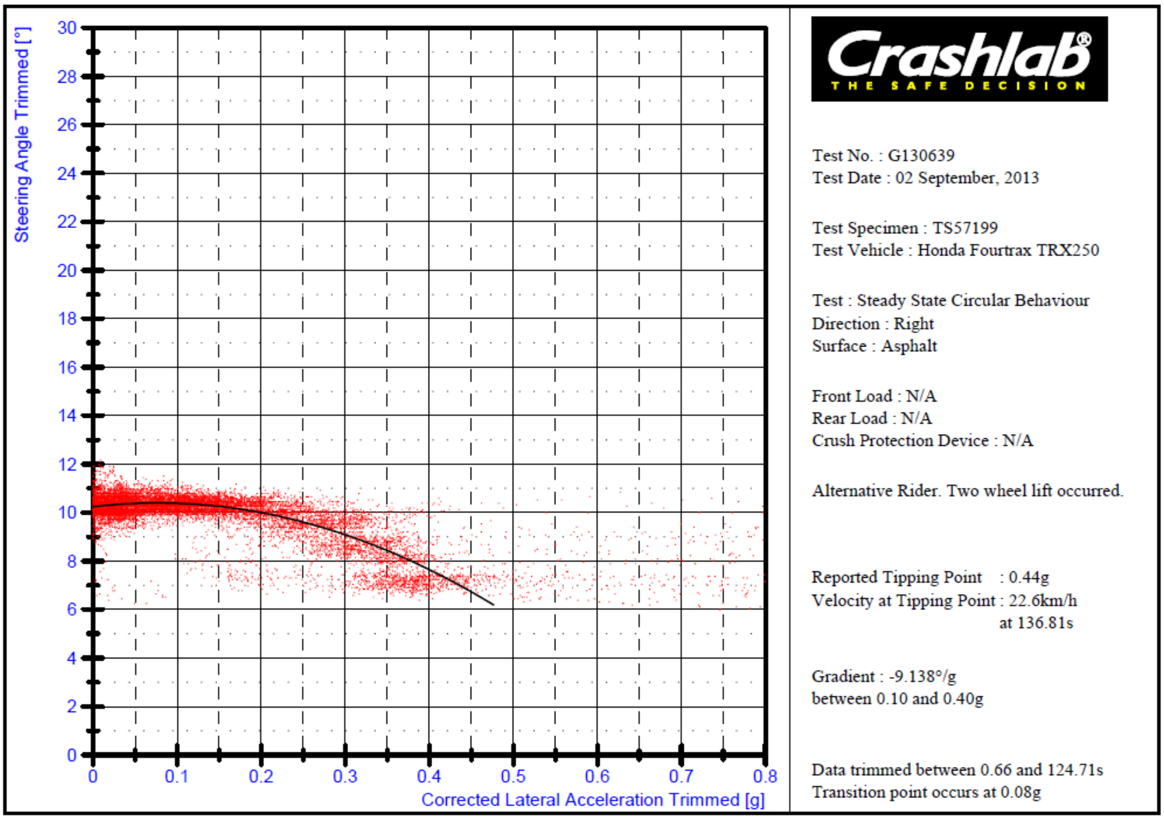
While the test series run to evaluate the effect of different riding positions was not a complete assessment of Active Riding style, the movement of the body implemented as shown in Figure 11 and Figure 12 at the most appropriate time provided a transient or dynamic benefit to vehicle stability beyond the simple variation to static stability that could be measured. It was a simplified series of tests to assess the effects of the rider leaning well forward, fully rearward and leaning into the circle as far as possible.

With Active Riding (asphalt), the dynamic stability values increased by approximately 13%, from 0.46g up to 0.52g (Table 2). These values were very similar to the tilt table TTRs (without Active Riding) of 0.51 (Table 1). Figure 31 shows the effect on oversteer/understeer of the rider seated at the reference point and when actively riding in the positions noted.

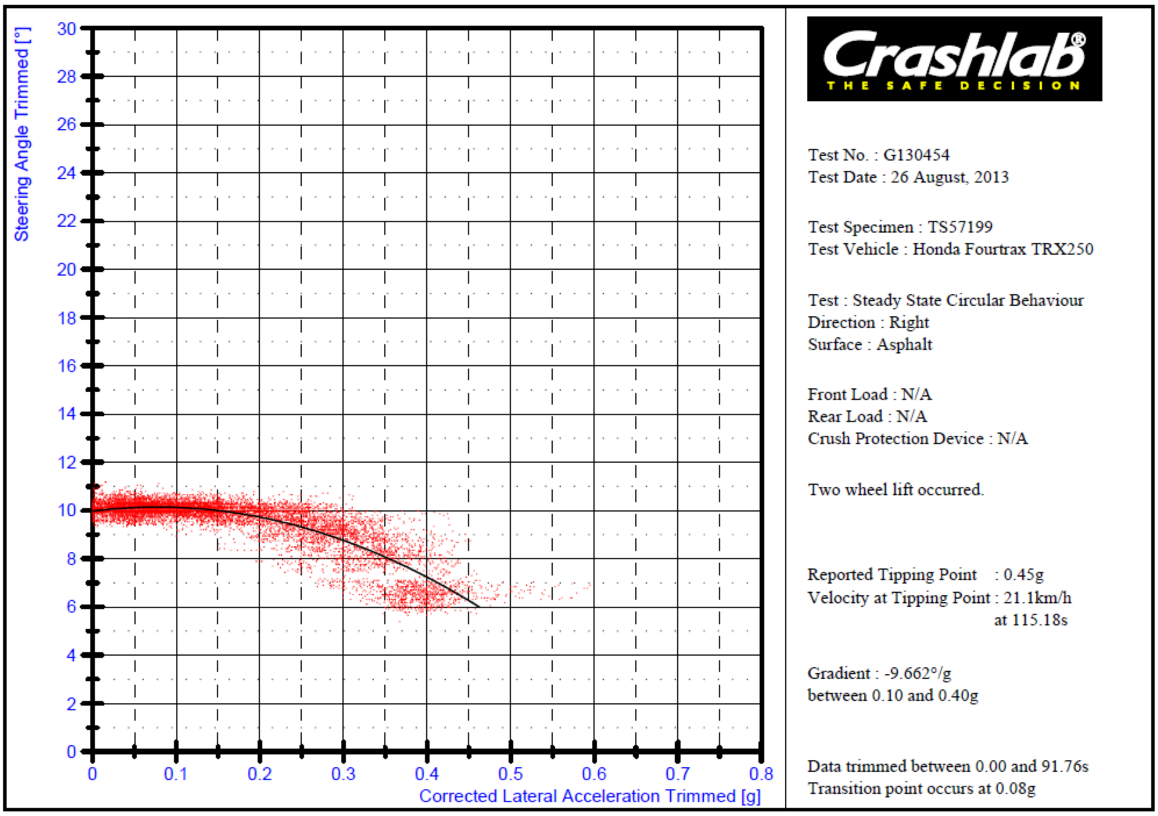
The results were in line with expectations and were in keeping with the principles of vehicle dynamics, which are well documented in the literature (Miliken, 2004, Gillespie, 1992). Leaning forward shifted the vehicle Center of Gravity (CoG) forward and hence improved understeer (decreased oversteer effect), and shifting the rider weight rearward shifted the CoG of the entire system rearward increasing oversteer. Note, on yielding surfaces, e.g., soft sand or mud, different effects may occur but were not part of this testing program.

Leaning into the corner resulted in shifting the vehicle CoG slightly forward (the rider could not reach the far side handgrip without moving forward slightly). This reduced oversteer and the inboard movement helped improve static stability and hence increased the lateral acceleration at which vehicle tip-up occurred.

While these results are not conclusive as to the exact benefits of an Active Riding style, they do strongly suggest that proper training and use of an Active Riding style are important to reduce the risk of rollover and can be used to increase the performance envelope of a Quad bike, should the rider so desire it.

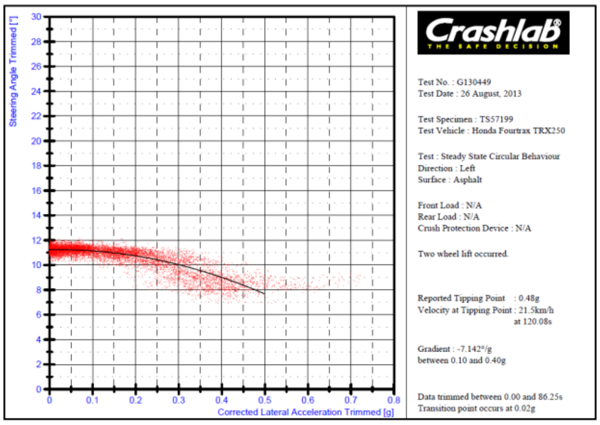


Rider 1

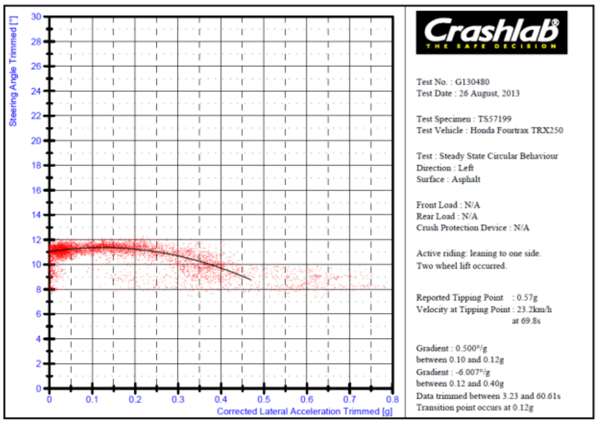


Rider 2

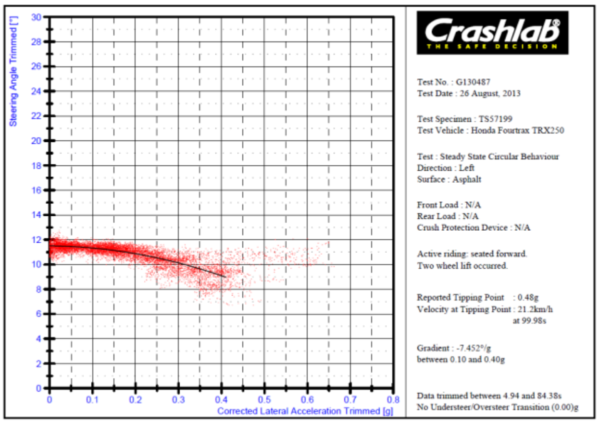
Figure 30: Understeer/oversteer graph for Honda Fourtrax TRX250 for two riders.



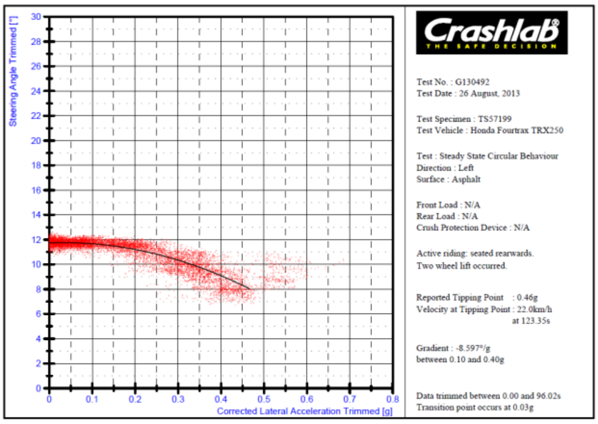
rider at seat reference point



rider leaning in and forward



rider sitting well forward



rider sitting well back

Figure 31: Effect on understeer/oversteer and tipping point of different riding positions.

2.3.7 Comparison with Standards

There are no standards or compliance requirements in Australia for Quad bikes or SSVs.

However, three United States of America (USA) standards exist, one of which is relevant to Quad bikes and two of which are relevant to SSVs. They are, respectively for Quad bikes: **ANSI/SVIA 1-2010**: American National Standard for Four Wheel All-Terrain Vehicles; and for SSVs: **ANSI/ROHVA 1-2011**: American National Standard for Recreational Off-Highway Vehicles, and also **ANSI/OPEI B71.9-2012:** American National Standard for Multipurpose Off-Highway Utility Vehicles. The difference between ANSI/ROHVA 1-2011 and ANSI/OPEI B71.9-2012 in terms of which SSV vehicle any respective standard applies to appears vague. In this project the research team referred to the ANSI/ROHVA 1-2011 standard for SSVs.

There are no dynamic handling requirements specified for Quad bikes in the ANSI/SVIA 1-2010: American National Standard for Four Wheel All-Terrain Vehicles.

For SSVs the ANSI/ROHVA 1-2011 standard sets out the following Dynamic Handling test requirements in Clause 8.3:

- Asphalt surface with friction co-efficient of at least 0.90.
- Vehicle loaded with driver plus equipment (including outriggers) of 195kg.

- Circle test, with a 7.6m radius.
- The vehicle drive train is set in its most-open setting, e.g. if possible, two-wheel drive shall be used instead of four-wheel drive, and a lockable differential, if so equipped, shall be in its unlocked, or “open,” setting.
- Vehicle is slowly accelerated until:
  a) a corrected lateral acceleration of at least 0.6g is reached; or
  b) a corrected lateral acceleration of at least 0.6g cannot be reached and:
    i. a two-wheel lift of two inches or more occurs; or
    ii. further increases in vehicle throttle input do not result in increases in vehicle speed.
- Tests are repeated 5 times for each direction (clockwise/ anticlockwise or left/ right).

While these exact test conditions were not used in the SSV testing, some similar but possibly more severe tests were carried out on two SSVs with results set out in Table 6. These results show that the two vehicles would very likely meet these ANSI /ROHVA 1-2011 minimum requirements of lateral acceleration exceeding 0.6g. The Authors consider that while SSVs in general demonstrate higher stability TTRs than Quad bikes, the Standard should nevertheless require higher dynamic stability limits of lateral acceleration. The Authors note that the most recent US CPSC’s study (US CPSC, 2014) recommends an increase in lateral stability in the current standards, to require a minimum lateral acceleration at tip up for SSVs of 0.70 g in a J turn test at 30 mph (48 km/h) to reduce the risk of rollover.

The issue concerning inadequacy of current standards regarding vehicle stability has also been discussed in detail in Part 1: Static Stability Test Results and Rating of 17 Quad bikes and Side by Side vehicles (SSVs) in Sections 3.5 and 4.4 and in particular Table 11 in that report lists the outcomes.

Make	Model	Surface	Loading	Average limit of lateral acceleration (g)		Dynamic vehicle outcome	
				Left	Right	Left	Right
Honda	Big red MUV700	Asphalt	Rear differential locked	0.75	0.67	Rear of the vehicle slid out causing vehicle to point towards the inside of the circle	Rear of the vehicle slid out causing vehicle to point towards the inside of the circle
Honda	Big red MUV700	Asphalt	Rear load (454kg)	0.62	0.55	Inside rear wheel broke traction (limiting speed)	Inside rear wheel broke traction (limiting speed)
Yamaha	Rhino 700	Asphalt	Rear load (181kg)	0.74	0.68	Two wheel lift	Two wheel lift

Table 6: Average limit of lateral acceleration (g) for two SSVs loaded, on asphalt.

3. DYNAMIC STABILITY AND HANDLING OVERALL RATING INDEX FOR THE 17 TEST VEHICLES

The Dynamic Handling Overall Rating Index is the second of the three major test components of the ATVAP Star rating system:

- Static Stability Tests
- Dynamic Stability Tests
- Crashworthiness Tests

The proposed Dynamic Handling Overall Rating Index is based on the summation of the index values from the following four dynamic test results with rider/ driver for each vehicle.

3.1 Points Ratings

Each test will be rated out of 5 points, with a total of 25 points, with points allocated as set out in Table 7**.**

1. **Steady-state circular driving dynamic tests** - the limit of lateral acceleration, Ay (g)
2. **Steady-state circular driving dynamic tests** - understeer/oversteer characteristics.
3. **Lateral transient response dynamic tests** - the steering response time.
4. **Bump obstacle perturbation tests** - the measured acceleration of the ATD's pelvis.

The total points for the Dynamic Handling Overall Rating Index (25) are similar to those proposed in the Static Stability rating. These are based upon the Authors' assessment that the risk of rollover is reduced by having higher rollover resistance, mild understeer, shorter yaw/steering response time, and minimal dummy resultant acceleration when traversing a bump with one wheel track (either left or right).

	Points rating				
Criteria	**1**	**2**	**3**	**4**	**5**
1. Lateral Stability Ay (g) at tip up (no tip up = 3 pts)	<0.4	0.4 to 0.59	0.6 to 0.79	0.8 to 0.99	>1.0
2. Steady State turning -Transition to oversteer (g)	<0.1	0.1 to 0.29	0.3 to 0.39	0.4 to 0.49	0.5
3. Steady State turning -Understeer Gradient (degree/g)	≥8.0	8.0 to 6.0	5.9 to 4.0	3.9 to 3.0	0.49 to 3.0
4. Steady State turning - Oversteer Gradient (degree/g)	≥ -8.0 Oversteer	-7.9 to -4.0 Oversteer	-3.8 to -1.0 Oversteer	-0.99 to 0.5 Neutral	0.49 to 3.0 Understeer
5. Steering response time (s)	>0.5	0.41 to 0.5	0.31 to 0.4	0.2 to 0.3	<0.2
6. Bump Obstacle Response - Pelvis acceleration (g)	>3.0	2.1 to 3.0	1.6 to 2.0	1.0 to 1.5	<1.0

Table 7: Summary of the allocation of Rating points for the Dynamic Handling Overall Rating Index (Max 25 points total)

3.2 The Dynamic Handling Overall Rating Index

For the 17 vehicles, the Rating for each of the 5 test categories, and the Weighted Index[17] is given in Table 8 and in bar-chart form in Figure 32.

The ‘Weighted Index’ is the ‘weighted’ sum of the 5 individual Rating values, with the weighting equal to 5.0 for each test. That is, each test is included with equal weighting, at this stage.

3.3 Observations from the Dynamic Handling Overall Rating Index

From these index results given in Table 8 and Figure 32 the following observations are made.

The SSVs, except for one model (14 points) all have higher overall indices with points from 18 to 20, compared with 10 to 12 for the work Quad bikes. One of the Recreation Quad bikes has a high rating of 16 points and the prototype Quad bike a rating of 17. The maximum rating is 25 points.

The modifications made to the prototype Quad bike vehicle’s track width, suspension system and differential, demonstrates that it is possible to modify a Quad bike to have better handling characteristics that are similar to an SSV. Had the prototype performed better in the bump test and understeer gradient, it could have potentially been the best performer in the ratings.

[17] Notes regarding Table 8 and Figure 32: For Test 5 for SSVs - the pelvic acceleration was not measured as testing identified that the bump test did not result in adverse perturbation of the SSV or driver, with a high positive Rating of ‘4’ being assigned to each of the SSVs, accordingly.

Dynamic Handling Overall Index Driver Only			1. Limit of Lateral Acceleration		2. & 3. Steady State Steering Characteristics				4. Lateral Transient Response		5. Bump Response		Weighted Index
Type	Make	Model	Ay (g)	1. Rating	Understeer Gradient (deg/g)	2. Rating	Transition Point (g)	3. Rating	Time (sec)	4. Rating	Pelvis Resultant Acceleration (g)	5. Rating	
SSV	Honda	MU700 Big Red	0.56 (no tip up)	3	3.6	4	n/a	5	0.27	4	1.5	4	20
SSV	Kubota	RTV500	0.54 (no tip up)	3	2.2	5	0.40	4	0.20	4	1.5	4	20
SSV	Tomcar	TM2	0.49 (no tip up)	3	5.3	3	n/a	5	0.20	4	1.5	4	19
SSV	John Deere	XUV825i	0.54 (no tip up)	3	6.5	2	n/a	5	0.27	4	1.5	4	18
SSV	Yamaha	Rhino	0.61	3	-8.7	1	0.19	2	0.28	4	1.5	4	14
Quad	Protoype		0.57 (no tip up)	3	7.8	2	n/a	5	0.12	5	2.1	2	17
Quad	Yamaha	YFM450F AP Grizzly	0.41	2	-4.4	2	0.18	2	0.14	5	1.9	3	14
Quad	Polaris	Sprotsman 450HO	0.55	2	-8.3	1	0.15	2	0.13	5	1.7	3	13
Quad	CF Moto	CF500	0.50	2	-4.4	2	0.03	1	0.20	4	1.8	3	12
Quad	Honda	TRX500FM	0.52	2	-4.4	2	n/a	1	0.17	5	2.1	2	12
Quad	Kawasaki	KVF300	0.46	2	-4.2	2	n/a	1	0.13	5	3.0	2	12
Quad	Suzuki	KingQuad400ASi	0.45	2	-8.6	1	0.01	1	0.16	5	2.2	2	11
Quad	Honda	TRX250	0.46	2	-8.8	1	0.06	1	0.13	5	2.8	2	11
Quad	Kymco	MXU300	0.36	1	-9.0	1	0.12	2	0.10	5	2.1	2	11
RQuad	Honda	TRX700XX	0.55	2	4.1	3	0.33	3	0.14	5	2.0	3	16
RQuad	Can-Am	DS90X	0.54	2	-3.9	3	0.18	2	0.15	5	3.5	1	13
RQuad	Yamaha	YFM250R Raptor	0.47	2	-8.0	1	0.01	1	0.15	5	3.1	1	10
													Max 25

Table 8: Dynamic Handling Overall Rating Index for the 17 vehicles, rider/ driver only (i.e. no added loads). Maximum rating = 25 points.

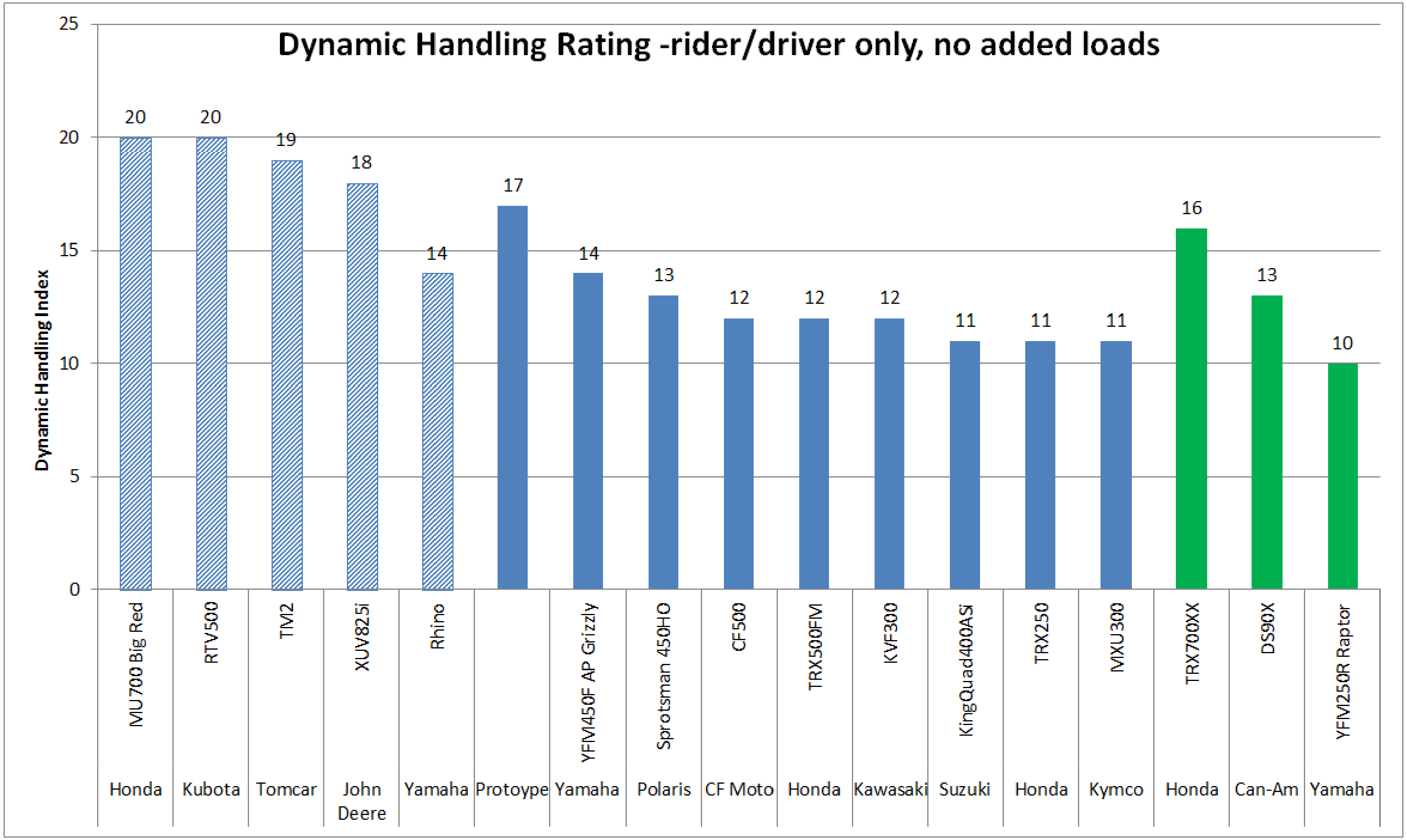


Figure 32: Bar chart showing the Dynamic Handling Overall Rating Index for the 17 vehicles, rider/ driver only (i.e. no added loads). Maximum rating =25 points.

4. CONCLUSIONS

4.1 The Dynamic Handling Test Results

Following on from the Static Stability test program for the 17 vehicles (includes the prototype Quad bike), the dynamic test program provides the second arm of the assessment and rating of the Quad bikes and SSVs for stability and handling. Improvements in Quad bike and SSV handling has been highlighted by authors such as Roberts (2009) and others as being practical means to reduce crash and rollover risk.

The Static Stability and Dynamic Handling ratings will be combined with Part 3 of the Quad Bike Performance Project which involves developing and testing the crashworthiness of the 17 vehicles, with the original objective being to develop the Australian Terrain Vehicle Assessment Program (ATVAP) relative safety rating system for crash and injury prevention. However, as information was not available during the current study that would link the test outcomes to real safety outcomes (i.e., fatality and injury data) for the specific make and model tested vehicles, this goal was not able to be achieved during this part of the project. Instead, a rating system based on the opinions of the research team, and stated assumptions about what dynamic handling characteristics would result in better performance for the workplace, was developed and applied.

The dynamic test program consisted of over 546 tests, in three different dynamic tests series[18], all relating to vehicle control and handling characteristics which the Authors consider will improve a driver/ rider's vehicle path control and the vehicle's resistance to rollover:

1. **Steady-state circular driving dynamic tests** to determine each vehicle's limit of lateral acceleration and the understeer/oversteer characteristics;
2. **Lateral transient response dynamic tests** to determine each vehicle's time taken to respond to a rapid steering input;
3. **Bump obstacle perturbation tests** to determine each vehicle's ability to ride over bumps with minimal change in steering direction or displacement of the rider/ driver.

These dynamic tests were also innovative and most significant as they showed that Quad bikes could be subject to scientifically reliable, reproducible, and meaningful Dynamic Handling tests. This finding was contrary to claims by some in industry that such testing was not feasible or meaningful.

In regards to repeatability and reproducibility, each test configuration was tested three times on different surfaces and with different riders, to establish results repeatability and reproducibility where all results are provided in tables contained in Appendix C of the Crashlab Report[18]. These results show good repeatability and reproducibility and confirm that Quad bikes can be reliably tested and rated for handling characteristics, and thus

[18] Refer the Crashlab Special Report SR2013/004 provided in **Attachment 1** of this report.

further demonstrate that improvements in handling are indeed possible, particularly when the Quad bikes are compared to the prototype Quad bike and SSVs.

The key findings from the dynamic tests are:

1. The results from the Dynamic Handling tests provide sufficient discrimination in the range of vehicles tested (Quad bikes and SSVs) to use as a basis for the rating system;
2. For the Quad bikes the measured minimum limit of lateral acceleration at tip up was in the range of 0.36g to 0.55g, and for each Quad bike was less than their tilt-table static stability TTR. The circle tests validated that the TTR value provides a valid measure of lateral stability (i.e. level of rollover resistance) of Quad bikes;
3. All the Quad bike's limit of lateral acceleration occurs by tipping up onto two wheels, which unless able to be counteracted by the rider, is a precursor to rollover or loss of control – that is, a loss of stability;
4. For the SSVs these showed higher lateral stability than the Quad bikes;
5. The three Quad bikes that were tested on asphalt and grass displayed very similar handling characteristics and tipped up at similar lateral acceleration values on both surfaces. Testing of Quad bikes on an asphalt surface did provide relevant, reproducible performance characteristics;
6. The Honda TRX250 Quad bike[19] was used as a representative Quad bike for comparing the effects of surface type, load combinations and Active Riding on lateral stability. With Active Riding (on asphalt), the dynamic stability values increased by approximately 13%, from 0.46g up to 0.52g. These values were very similar to the tilt table TTRs (without Active Riding) of 0.51;
7. The representative Quad bike (Honda TRX250) when tested with the Quadbar and Lifeguard OPDs, showed only a minor change in limit of lateral acceleration (0.46g down to 0.45g);
8. The results overall obtained show that most Quad bikes tested for this program have an oversteer characteristic, which is not a favourable characteristics for most rider situations. Notably, the Honda TRX700 recreational Quad bike, showed a light understeer characteristic of around 2 degrees per g through to above 0.33g and then transitioned to a light oversteer characteristic. This is considered a very good steering characteristic and demonstrates that it is quite possible to design the steering system of a Quad bike to produce the recommended handling results;
9. All vehicles tested unloaded on asphalt had steering response times of less than 0.3 seconds, with a significant number of the vehicles displaying steering response times of less than 0.2 seconds (see Figure 23), which is generally satisfactory;

[19] A 'representative' Quad was selected for these comparison tests. It was beyond the scope and budget of this dynamic test program to be able to test all of the 17 vehicles in all load and surface combinations. As noted well in excess of 546 tests were conducted in this dynamic test program alone.

10. The ‘bump tests’ identified, possibly for the first time, a significant mechanism in which Quad bikes riders can (and apparently do) lose control in what appears to be a low risk scenario, i.e. going over moderate bump (such as a log, small rock, small mound, rut, rabbit hole, etc.), where the rider and Quad bike is displaced excessively laterally whilst traversing the ‘bump’. In an attempt to pull themselves back onto the seat, the rider can pull on the handle bar, or inadvertently accelerate the vehicle via the thumb throttle, further exacerbating the turn of the Quad bike leading to rollover. All of the SSVs traversed the bump satisfactorily, with low level of rider or vehicle perturbation;
11. The Authors note that the most recent US CPSC’s study (US CPSC, 2014) recommends an increase in lateral stability in the current standards, to require a minimum lateral acceleration at tip up for SSVs of 0.70 g in a J turn test at 30 mph (48 km/h) to reduce the risk of rollover.
12. In contrast to the Quad bikes, SSVs had more forgiving handling and higher stability characteristics (i.e. higher resistance to rollover), and are less reliant on operator vehicle handling skills.

Finally, in order to handle well (consistently and safely) and reduce the risk of a loss of control crash occurring, a Quad bike or SSV, like any other self-propelled vehicle, should have a slight understeer characteristic when excited between 0.1 and 0.5g lateral acceleration and a lateral transient steering response of less than 0.25 - 0.3 seconds. In addition, the vehicle suspension should be designed so as to minimise both the disturbance and displacement of the rider or driver when engaging an asymmetric bump type obstacle.

The Authors are strongly of the opinion that history has clearly demonstrated that advances in safety for all types of land mobile vehicles are correlated with improvements in stability, handling and crashworthiness. Indeed, the Authors agree with the latest September 2014 report and proposed rulemaking by the US Consumer Product Safety Commission (CPSC, 2014) regarding improved handling and stability for SSVs (see Section 2.2.1).

4.2 The Dynamic Handling Overall Rating Index and Further Research

From the index results given in Table 8 and Figure 32 the following observations are made:

The SSVs, except for one model (14 points) all have higher overall indices than the work Quad bikes, with points from 18 to 20, compared with 10 to 12 for the work Quad bikes. One of the Recreation Quad bikes has a high rating of 17 points and the prototype Quad bike a rating of 17. The maximum rating is 25 points.

The Authors recommend further research be conducted in order to:

a. Determine the relative weightings of vehicle safety discriminating factors that are to be applied, based on analysis of Make, Model and Year (MMY)-specific fatal and injury crash data;
b. Improve the efficacy of the Bump Obstacle Perturbation Test by understanding and assessing vehicle yaw, rider upper body deflection and steering input; and

c. Monitor the continuing safety rating program in order to fine tune the discriminating factors based on on-going crash data and developments in vehicle safety technologies.

Signed:

Prof. Raphael Grzebieta,
Team Leader,
Quad Bike Performance Project
Ph: 02 9385 4479 (Int: +61 2 9385 4479)
Mb: 0411 234 057 (Int: +61 411 234 057)
Email: r.grzebieta@unsw.edu.au
Web: www.tars.unsw.edu.au

Assoc. Prof. George Rechnitzer (Adjunct)
Project Manager,
Quad Bike Performance Project
Mb: 0418 884 174 (Int: +61 418 884 174)
Email: g.rechnitzer@unsw.edu.au
Web: www.tars.unsw.edu.au

Mr. Keith Simmons
Project Consultant,
Quad Bike Performance Project
Mobile 0439 404 901 (Int: +61 439 404 901)
Email: keith_simmons@bigpond.com

5. References

1. American National Standard for Four Wheel All-Terrain Vehicles ANSI/SVIA 1 - 2010, Developed by Specialty Vehicles Institute of America (SVIA), Approved by American National Standards Institute (ANSI) 12/23/10, Published by Specialty Vehicle institute of America, 2 Jenner, Suite 150, Irvine California 92618-3806
2. American National Standard for Recreational Off-Highway Vehicles ANSI.ROHVA 1 - 2011, American National Standard Institute, 11 July 2011
3. Denning GM, Harland KK, Ellis DG, and Jennissen CA. More fatal all-terrain vehicle crashes occur on the roadway than off: increased risk-taking characterises roadway fatalities. Department of Emergency Medicine, University of Iowa. Published in Injury Prevention, August 2013.
4. Department Of Infrastructure, Energy and Resources (DIER), SRT Calculator User Guide, TERNZ Ltd, Manukau, New Zealand, 25 May 2006.
5. Federal Chamber of Automotive Industries (FCAI), FCAI Position on University of New South Wales, Quad Bike Performance Project, September, 2013.
6. Gillespie, TD, Fundamentals of Vehicle Dynamics, SAE Publications, 1992.
7. Heydinger, Gary J. Vehicle Characteristics Measurements of Recreational Off-Highway Vehicles; for US Consumer Product Safety Commission, February 2011
8. Heydinger, G.J., Bixel, R., Jebode, H., Peterman, E., Sidhu, A., Vehicle Characteristics Measurements of Recreational Off-Highway Vehicles, CPSC, April, 2011.
9. ISO 4138:2004, Passenger cars—Steadystate circular driving behavior—Open-loop test methods, Third edition 2004-09-15, International Organization for Standardization, 2004.
10. ISO 7401 Road Vehicles - Lateral Transient Response Test Methods - Open Loop Test Methods
11. Juregnsohn Thomas, Modelling Driver Behaviour in Automotive Environments, 2007
12. Lee, T., Kang, J., Yi, K., Noh, K. et al., Integration of Longitudinal and Lateral Human Driver Models for Evaluation of the Vehicle Active Safety Systems, SAE Technical Paper 2010-01-0084, 2010, doi:10.4271/2010-01-0084.
13. Lower T, Herde E, Fragar L. Quad bike deaths in Australia 2001 to 10. *Journal of Health, Safety & Environment* 2012.
14. Mengert, P., Salvatore, S., DiSario, R., Walter, R., Statistical estimation of rollover risk, DOT-HS-807-466, U.S. Department of Transportation, August 1989.
15. Macadam C C., Understanding and Modelling the Human Drive, Vehicle Systems Dynamics Vol 40, 2003
16. McIntosh A.S. and Patton D., (2014). Quad Bike Fatalities in Australia: Examination of NCIS Case Data - Crash Circumstances and Injury, Quad Bike Performance Project, Supplemental Report, Attachment 1, Transport and Road Safety (TARS) Research Report for The WorkCover Authority of New South Wales, University of New South Wales, Sydney, Australia.
17. McRuer, D.T.: Human Dynamics in Man–Machine Systems. Automatica 16 (1980)

18. McRuer, D.T., Allen, R.W. and Klein, R.H : New Results in Driver Steering Control Models. Human Factors: The Journal of the Human Factors and Ergonomics Society, Volume 19, pp 381 - 397, 1977
19. McRuer, Duane T., Klein, Richard H., Automobile Controllability – Driver/Vehicle Response for Steering Control, DOT-HS-801-407, Volume 1, February 1975.
20. Milliken W, Milliken D and Olley M. Chassis Design; Principles and Analysis, SAE Publications, ISBN 978-0-7680-0826-5, 2002.
21. Milliken, Notes of Vehicle Dynamics – Maurice Olley, SAE publications, 2004.
22. Milliken, W. and Milliken, D., Race Car Vehicle Dynamics, SAE Publications, 1995
23. Mitchell, R (2014). All-terrain vehicle-related fatal and non-fatal injuries: Examination of injury patterns and crash circumstances, Supplemental Report, Attachment 2, Transport and Road Safety (TARS) Research Report for The WorkCover Authority of New South Wales, University of New South Wales, Sydney, Australia.
24. Rechnitzer, G., Grzebieta R.H., McIntosh A.S., and Simmons K. (2013). Reducing All Terrain Vehicle Injuries (ATVs) And Deaths - A Way Ahead, Proc. 23rd International Safety Conference on the Enhanced Safety of Vehicles, Soeul, Korea, May, Paper No. 13-0213.
25. Renfroe David A., Effects of Surface Anomalies and Tire Mechanics on ATV Tire Friction Coefficients, SAE Paper 96100, February 1996
26. Roberts A, "Dynamic Analysis of Side-by-Side Utility and Recreational Vehicles", Paper No.09-0260-O, 21st International Safety Conference on the Enhanced Safety of Vehicles, 2009.
27. SAE J266, Steady-State Directional Control Test Procedures for Passenger Cars and Light Trucks, Society of Automotive Engineers, 1996.
28. Segel, L, Research In the Fundamentals of Automobile Control and Stability, Transactions of the SAE, 1956.
29. US Consumer Product Safety Commission (CPSC) 2014. Safety Standard for Recreational Off-Highway Vehicles (ROVs), Notice of Proposed Rulemaking, 16 CFR Part 1422, RIN 3041-AC78, Docket No. CPSC-2009-0087.
30. US Consumer Product Safety Commission (CPSC) 2011. Annual Report of ATV Related Deaths and Injuries February 2013
31. US Consumer Product Safety Commission, Advanced Notification of Proposed Regulation for Standard for Recreational Off-Highway Vehicles, Federal Register/Vol. 74, No. 207, October 28, 2009.
32. US Consumer Product Safety Commission - Annual Report into ATV related fatalities and injuries, 2011, available at http://www.cpsc.gov//Global/Research-and-Statistics/Injury-Statistics/atv2011.pdf
33. US Consumer Safety Product Commission, Advance Notice of Proposed Rulemaking: Recreational Off-Highway Vehicles, Briefing Package for Recreational Off-Highway Vehicles (ROVs), Oct, 2009, http://www.cpsc.gov/PageFiles/89904/offhighway.pdf
34. Weir, D H. and Di Marco, R J., (1978). Correlation and Evaluation of Driver/Vehicle Directional Handling Data, SAE 780010.

35. Weir D.H. and Zellner J.W. An Introduction to the Operational Characteristics of All-Terrain Vehicles; SAE Technical Paper Series. Dynamic Research Inc, Torrance CA, 1986

36. Weir, D., DiMarco, R.J. and McRuer, D.T.: Evaluation and Correlation of Driver/Vehicle Data, Vol II, in Final Technical Report, NHTSA, DOT-HS-803-246, 1977.

6. Appendix 1: Copy of US CPSC letter to ROVA dated 28th August 2013

U.S. CONSUMER PRODUCT SAFETY COMMISSION
4330 EAST WEST HIGHWAY
BETHESDA, MD 20814

Caroleene Paul
Mechanical Engineer
Division of Mechanical Engineering
Directorate for Engineering Sciences

Tel: 301-987-2225
Fax: 301-504-0533
Email: cpaul@cpsc.gov

August 29, 2013

Mr. Paul Vitrano
Executive Vice President & General Counsel
Recreational Off-Highway Vehicle Association
2 Jenner Street, Suite 150
Irvine, California 92618-3806

Dear Mr. Vitrano:

The U.S. Consumer Product Safety Commission (CPSC) staff has participated in the Canvass Method used by the Recreational Off-Highway Vehicle Association (ROHVA) to develop the American National Standard, ANSI/ROHVA 1-2011 *Recreational Off-Highway Vehicles*.[1] In comment letters to the ballots for the draft proposed standards and draft proposed revision to the standard, CPSC staff has stated its concerns regarding the need for a ROV standard to have robust lateral stability requirements, vehicle handling requirements that ensure sub-limit understeer performance, and robust occupant protection requirements that maximize occupant retention performance.

CPSC staff urges the ANSI/ROHVA voluntary standard subcommittee to immediately consider incorporating the attached additional requirements and changes that staff suggests be made to the ANSI/ROHVA voluntary standard in order to improve ROV safety requirements for lateral stability, vehicle handling, and occupant protection. Please find enclosed the suggested requirements for your consideration in Appendix A.

A staff review of ROV-related incidents, as noted in Appendix B, occurring between January 1, 2003, and December 21, 2011, revealed 428 reported incidents resulting in 388 injured victims and 231 fatalities. CPSC staff looks forward to continuing to work with ROHVA to make these important changes to the ANSI/ROVHA voluntary standard to better address injuries and deaths associated with ROV rollover incidents. If you have any questions or comments, please feel free to contact me.

Sincerely,

Caroleene Paul

[1] The comments in this letter are those of the CPSC staff and have not been reviewed or approved by, and may not necessarily reflect the views of, the Commission.

CPSC Hotline: 1-800-638-CPSC (2772) ★ CPSC's Web Site: http://www.cpsc.gov

Appendix A: CPSC Staff Suggested Changes to ANSI/ROHVA 1-2011

A. Definitions

A.1 Recreational Off-Highway Vehicle (ROV). A motorized vehicle designed for off-highway use with the following features: four or more wheels with pneumatic tires; side-by-side seating for two or more occupants; automotive-type controls for steering, throttle, and braking; rollover protective structure (ROPS); seat restraint; and maximum speed capability greater than 30 mph.

A.2 Single-Hand Single-Operation Barrier. An occupant restraint component or assembly that is attached or actuated using a single operation with a single hand. As an example, a door may be opened using a single hand. A net system that requires the user to operate multiple attachment points to enter or exit the vehicle is not a single-hand single-operation barrier.

CPSC staff recommends that the following section, *Dynamic Lateral Stability*, replace section 8.3 *Dynamic Stability* in ANSI/ROHVA 1-2011.

B. Dynamic Lateral Stability

B.1 Test Surface. Tests shall be conducted on a dry, uniform, paved surface. Surfaces with irregularities, such as dips and large cracks, are unsuitable, as they may confound test results.

B.1.1 Friction. Surface used for dynamic testing shall have a peak braking coefficient greater than or equal to 0.90 and a sliding skid coefficient greater than or equal to 0.80 when measured in accordance with ASTM E 1337.

B.1.2 Slope. The test surface shall be flat and have a slope equal to or less than 1 degree (1.7%).

B.1.3 Ambient Conditions. The ambient temperature shall be between 0° Celsius (32 ° Fahrenheit) and 40 ° C (104 ° F). The maximum wind speed shall be no greater than 8 m/s (18 mph).

B.2 Test Conditions.

B.2.1 Vehicle Condition. A vehicle used for dynamic testing shall be configured in the following manner.

(1) The test vehicle shall be a representative production vehicle. The ROV shall be in standard condition, without accessories. The ROV and components shall be assembled and adjusted according to the manufacturer's instructions and specifications.

(2) The vehicle shall be operated in two wheel drive mode with selectable differential locks off during the conduct of the tests. The tires shall be the manufacturer's original equipment tires. The tires shall be scuffed or lightly broken-in, but otherwise new. Heavily worn tires shall not be used for handling verification testing.

(3) Springs or shocks that have adjustable spring or damping rates shall be set to the manufacturer's recommended settings for delivery and general use.

(4) Tires shall be inflated to the ROV manufacturer's recommended settings for normal operation for the load condition specified in B.2.1(6). If more than one pressure is specified, the lowest value shall be used.

(5) All fluids shall be at the recommended level and the fuel tank shall be full at the rated capacity.

(6) The ROV shall be loaded such that the combined weight of the test operator, test equipment (including outriggers), and ballast, if any, shall equal 195 kg ± 5 kg (430 lbs ± 11 lbs) unless the ROV is intended for a single person, in which case the combined weight of the test operator, test equipment (including outriggers) and ballast, if any, shall equal 98 kg ± 5 kg (215 lbs ± 11 lbs) [note: the test operator weight may be less than 98 kg (215 lbs) so long as the combined weight of the test operator, test equipment (including outriggers) and ballast, if any, equals 98 kg ± 5 kg (215 lbs ± 11 lbs).

(7) The test loading condition shall simulate the test vehicle's center of gravity (CG) location, with the required load condition, to within a total of 1.0 inches, with the exception that the displacement of the CG z-axis may not be more than 0.5 inches in the positive direction in a z-down-positive coordinate system.

B.2.2 Vehicle Test Equipment.

B.2.2.1 Safety Equipment. Test vehicles shall be equipped with outrigger(s) on both sides of the vehicle. The outriggers shall be designed to minimally affect the loaded vehicle's center of gravity location and shall be capable of preventing a full vehicle rollover.

B.2.2.2 Steering Controller. The test vehicle shall be equipped with a programmable steering controller (PSC) capable of responding to vehicle speed, with a minimum steering angle input rate of 500 degrees per second, and accurate within ± 1 degree. The steering wheel setting for 0.0 degrees of steering angle is defined as the setting which controls the properly aligned vehicle to travel in a straight path on a level surface. The PSC shall be operated in absolute steering mode in that the amount of steering used for each test shall be measured relative to the PSC reading when the vehicle steering is at zero degrees.

B.2.2.3 Vehicle Instrumentation. The vehicle shall be instrumented to record lateral acceleration, vertical acceleration, forward speed, steering wheel angle, steering wheel angle rate, and vehicle roll angle. See Table 1 for instrumentation specifications. Ground plane lateral acceleration shall be calculated by correcting the body fixed acceleration for roll angle. Ground plane lateral acceleration shall also be corrected to reflect the value at the test vehicle center of gravity (CG) location. A roll motion inertia measurement sensor that provides direct output of ground plane lateral acceleration at the vehicle CG may also be used in lieu of manual correction to obtain ground plane lateral acceleration. Video with time display may be employed for the determination of two wheel lift. Roll angle may be calculated from roll rate data. Other instrumentation may be used to facilitate the processing of data or to collect other data not directly associated with the J-turn maneuver.

Table 1. Instrumentation Specification
For J-Turn and Turn Circle Testing of ROVs

Parameter	Accuracy
Vehicle Speed	± 0.10 mph
Acceleration (x, y, and z directions)	± 0.003 g
Steering Wheel Angle	± 0.25 deg.
Steering Wheel Angle Rate	± 0.5 deg./sec.
Pitch, Roll, and Yaw Rates	± 0.10 deg./sec.
Roll Angle*	± 0.20 deg.

* For turn circle testing roll angle must be measured directly or roll rate accuracy must be ± 0.01 deg./sec.

B.3 Test Procedure.

B.3.1 Set the vehicle drive train in its most-open setting. For example, two-wheel drive shall be used instead of four-wheel drive, and a lockable differential, if so equipped, shall be in its unlocked, or "open," setting.

B.3.2 Drive the vehicle in a straight path to define zero degree (0.0) steer angle.

B.3.3 Program the PSC to engage at 30 mph with an input steer angle of 90 degrees to the right, with a minimum steering angle input rate of 500 degrees per second. Program the PSC to hold steering angles for a minimum of 4 seconds before returning to zero. The steering rate when returning to zero may be less than 500 degrees per second.

B.3.4 Conduct a 30 mph drop throttle J-turn.

B.3.4.1 Accelerate the vehicle in a straight line to a speed greater than 30 mph.

B.3.4.2 As the vehicle approaches the desired test location, engage the PSC and release the throttle.

B.3.4.3 The PSC will input the programmed steering angle when the vehicle decelerates to 30 mph. Verify that the instrumentation recorded all data during this J-turn event.

B.3.5 Conduct additional J-turns, increasing the steer angle in 10 degree increments as required until a two wheel lift event is achieved.

B.3.6 Conduct additional J-turns, decreasing the steering angle in 5 degree increments to find the lowest steering angle that will produce a two wheel lift event. Additional adjustments, up or down, in one degree increments may be utilized.

B.3.7 Repeat iterative process of conducting J-turns to determine minimum steer angle to produce two wheel lift in left turn direction.

B.3.8 Start the data acquisition system.

B.3.9 Conduct trials in the left and right directions using the minimum steering angles determined in Section 4.3.7 and 4.3.8 to verify that the steering angle produces two wheel lift events in both directions.

B.3.10 Conduct five trials with visually verified two wheel lift in the left and right turn directions and upslope and downslope directions, which will result in 20 total J-turn tests to complete the minimum data set. Review all data parameters for each trial to verify that all trials were correctly executed. Any trials that do not produce two wheel lift should be diagnosed for cause. If cause is identified, the data may be discarded and the trial should be repeated to replace the data. If no cause can be identified, repeat 4.3.5 through 4.3.7 to assure that the correct steering angle has been determined. Additional J-turn tests may be added to the minimum data set in groups of four with one test for each left/right turn direction and one test for each up/down slope direction on the test surface.

B.3.11 Determine LATERAL ACCELERATION THRESHOLD AT ROLLOVER value.

B.3.11.1 Data recorded in section B.3.10 shall be digitally low-pass filtered to 2.0 hertz using a phaseless, eighth order, Butterworth filter to eliminate noise artifacts in the data.

B.3.11.2 Plot data for ground plane lateral acceleration corrected to the test vehicle CG location, hand-wheel steer angle, and roll angle recorded for each trial in section B.3.10.

B.3.11.3 Find and record the peak ground plane lateral acceleration occurring between the time of the steering input and the time of two wheel lift and having a duration of at least 0.1 seconds.

B.3.11.4 If a body-fixed acceleration sensor is used, correct the lateral acceleration data for roll angle using the method described in the standard ANSI/ROHVA 1-2011:

Calculate ground-referenced lateral acceleration for each data sample. The data for Ay, Az, and roll angle are measured in the vehicle XYZ coordinate system (as defined in SAE J670 ® Vehicle Dynamics Terminology). The corrected lateral acceleration (Ay ground) shall be calculated by:

Ay ground = Ay cos Phi – Az sin Phi

B.4 Performance Requirements. The minimum value for the LATERAL ACCELERATION THRESHOLD AT ROLLOVER shall be 0.70 g or greater.

<u>CPSC staff recommends that the following section, *Consumer Information Requirements*, be added to ANSI/ROHVA 1-2011.</u>

B.5 Consumer Information Requirements. Every ROV shall be offered for sale with a hang tag that provides information on the LATERAL ACCELERATION THRESHOLD AT ROLLOVER value of that model vehicle. The tag shall be attached to the ROV and may only be removed by the first purchaser.

B.5.1 Size. Every hang tag shall be at least 6 inches (152 mm) wide by 4 inches (102 mm) tall.

B.5.2 Content. At a minimum, every hang tag shall contain the following.

B.5.2.1 The LATERAL ACCELERATION THRESHOLD AT ROLLOVER value of the vehicle on a progressive scale.

B.5.2.2 The statement – "**Compare** with other vehicles before you buy."

B.5.2.3 The statement – "This is a measure of the vehicle's resistance to rolling over on a flat surface. ROVs with higher numbers are more stable."

B.5.2.4 The statement – "Other vehicles may have a higher rollover resistance; compare before you buy."

B.5.2.5 The statement – "Rollover cannot be completely eliminated for any vehicle."

B.5.2.6 The statement – " Minimally accepted lateral acceleration is 0.7 g's during a J-turn test."

B.5.3 Format. The hang tag shall include the content and substantially the same format as shown in Figure 1.

B.5.4 Attachment. Every hang tag shall be attached to the ROV in such a manner as to be conspicuous and removable only with deliberate effort.

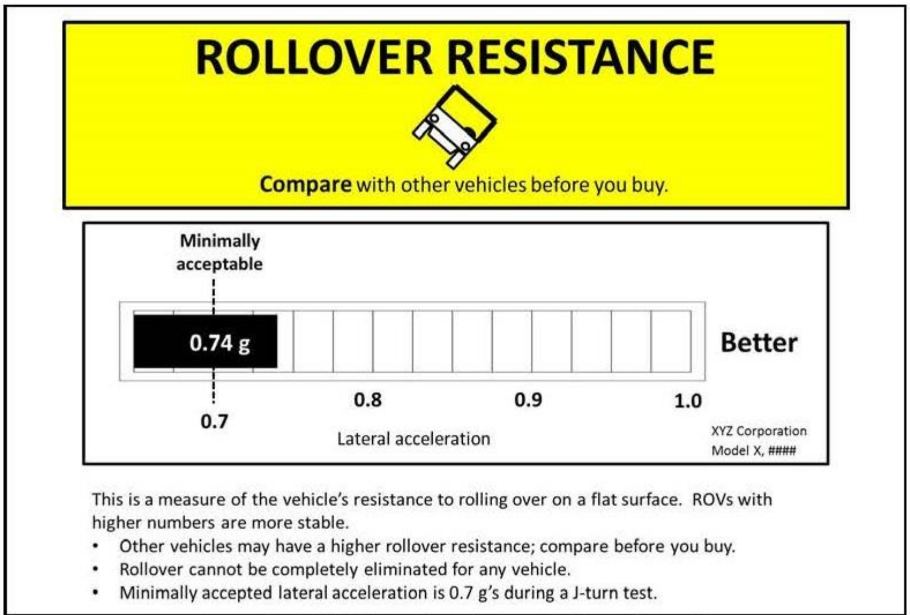


Figure 1. ROV Hang Tag (note: not shown to scale)

CPSC staff recommends that the following section, *Vehicle Handling*, be added to ANSI/ROHVA 1-2011.

C. Vehicle Handling

C.1 Test Surface. Tests shall be conducted on a dry, uniform, paved surface. Surfaces with irregularities, such as dips and large cracks, are unsuitable, as they may confound test results.

C.1.1 Friction. Surface used for dynamic testing shall have a peak braking coefficient greater than or equal to 0.90 and a sliding skid coefficient greater than or equal to 0.80 when measured in accordance with ASTM E 1337.

C.1.2 Slope. The test surface shall be flat and have a slope equal to or less than 1 degree (1.7 %).

C.1.3 Ambient Conditions. The ambient temperature shall be between 0° C (32 ° F) and 40 ° C (104 ° F). The maximum wind speed shall be no greater than 8 m/s (18 mph).

C.2 Test Conditions.

C.2.1 Vehicle Condition. A vehicle used for dynamic testing shall be configured in the following manner.

(1) The test vehicle shall be a representative production vehicle. The ROV shall be in standard condition, without accessories. The ROV and components shall be assembled and adjusted according to the manufacturer's instructions and specifications.

(2) The vehicle shall be operated in two wheel drive mode with selectable differential locks off during the conduct of the tests. The tires shall be the manufacturer's original equipment tires. The tires shall be scuffed or lightly broken-in, but otherwise new. Heavily worn tires shall not be used for handling verification testing.

(3) Springs or shocks that have adjustable spring or damping rates shall be set to the manufacturer's recommended settings for delivery and general use.

(4) Tires shall be inflated to the ROV manufacturer's recommended settings for normal operation for the load condition specified in C.2.1(6). If more than one pressure is specified, the lowest value shall be used.

(5) All fluids shall be at the recommended level and the fuel tank shall be full at the rated capacity.

(6) The ROV shall be loaded such that the combined weight of the test operator, test equipment (including outriggers), and ballast, if any, shall equal 195 kg ± 5 kg (430 lbs ± 11 lbs) unless the ROV is intended for a single person, in which case the combined weight of the test operator, test equipment (including outriggers) and ballast, if any, shall equal 98 kg ± 5 kg (215 lbs ± 11 lbs) [note: the test operator weight may be less than 98 kg (215 lbs) so long as the combined weight of the test operator, test equipment (including outriggers) and ballast, if any, equals 98 kg ± 5 kg (215 lbs ± 11 lbs).

(7) The test loading condition shall simulate the test vehicle's center of gravity (CG) location, with the required load condition, to within a total of 1.0 inches, with the exception that the displacement of the CG z-axis may not be more than 0.5 inches in the positive direction in a z-down-positive coordinate system.

C.2.2 Vehicle Test Equipment.

C.2.2.1 Safety Equipment. Test vehicles shall be equipped with outrigger(s) on both sides of the vehicle. The outriggers shall be designed to minimally affect the loaded vehicle's center of gravity location and shall be strong enough to prevent vehicle rollover.

C.2.2.2 Vehicle Instrumentation. The vehicle shall be instrumented to record lateral acceleration, vertical acceleration, forward speed, steering wheel angle, steering wheel angle rate, and vehicle roll angle. See Table 1 for instrumentation specifications. Lateral acceleration shall be corrected for roll angle and to reflect the value at the center of gravity location. A roll motion inertia measurement sensor that provides direct output of ground plane lateral acceleration at the vehicle CG may also be used in lieu of manual correction to obtain ground plane lateral acceleration. Other instrumentation may be used to facilitate the processing of data or to collect other data not directly associated with the vehicle handling test maneuver.

C.3 Test Procedure.

C.3.1 Handling performance testing shall be conducted using the constant radius test method described in SAE Surface Vehicle Recommended Practice J266. The minimum radius for constant radius testing shall be 100 feet. In this test method the instrumented and loaded vehicle is driven around a constant radius circle marked on the test surface with the driver making every effort to maintain compliance of the vehicle path relative to the circle. The vehicle is operated at a variety of increasing speeds and data is recorded for those various speed conditions in order to obtain data to describe the vehicle handling behavior across the prescribed range of ground plane lateral accelerations. Data shall be recorded for the lateral acceleration range from 0.0 g to 0.6 g.

C.3.2 Start the data acquisition system.

C.3.3 Drive the vehicle on the circular path at the lowest possible speed. Data shall be recorded with the steering wheel position and throttle position fixed to record the approximate Ackerman angle.

C.3.4 Continue driving the vehicle to the next speed at which data will be taken. The level of lateral acceleration shall be increased and data shall be taken until it is no longer possible to maintain steady-state conditions. It is recommended that the test be repeated several times, so that results can be examined for repeatability and averaged.

C.3.5 Data Collection, Method 1 – Discrete Data Points. In this data acquisition method, the driver maintains a constant speed while maintaining compliance with the circular path and data points are recorded when a relatively stable condition is achieved. After the desired data points are recorded for a given speed, the driver accelerates to the next desired speed setting, maintains constant speed and compliance with the path, and data points are recorded for the new speed setting. This process is repeated for all speed settings required to map the lateral acceleration range from near 0.0 g to 0.6 g. Increments of speed shall be 1 to 2 miles per hour, to allow for a complete definition of the understeer gradient. Data shall be taken at the lowest speed practicable to obtain an approximation of the vehicle's Ackerman steering angle. Driver work load is high for this test method; therefore, data point selection should be accomplished by an observer that is not aboard the vehicle.

C.3.6 Data Collection, Method 2 – Continuous Data Points. In this data acquisition method, the driver maintains compliance with the circular path while slowly increasing vehicle speed and data from the vehicle instrumentation is recorded continuously, so long as the vehicle remains on radius. The rate of speed increase shall not exceed 0.93 mph (1.5 km/h) per second. Initial speed should be as low as is practicable to obtain an approximation of the vehicle's Ackerman steering angle. The speed range must be sufficient to produce corrected lateral accelerations from near 0.0 g to 0.6 g. Data above the target value for ground plane lateral acceleration is required to produce a representative curve fit of the data.

C.3.7 Vehicle Dimension Coordinate System. The coordinate system described in SAE Surface Vehicle Recommended Practice J670 shall be used.

C.3.8 Data Analysis. The lateral acceleration data shall be corrected for roll angle using the ROHVA method described in the standard ANSI ROHVA 1 - 2011. The ground plane lateral acceleration shall also be corrected to reflect the value at the test vehicle's center of gravity. The data shall be digitally low-pass filtered to 1.0 Hz using a phaseless, eighth-order, Butterworth filter and plotted with ground plane lateral acceleration on the abscissa versus steering wheel angle (not road wheel steer angle) on the ordinate. A second-order polynomial curve fit to the data shall be constructed in the range from 0.01 g to 0.50 g. The slope of the constructed graph determines the understeer gradient value in the units of degrees of steering wheel angle per g of ground plane lateral acceleration (degrees/g). Using the coordinate system specified in C.3.7, positive values for understeer gradient are required for values of ground plane lateral acceleration values from 0.10 g to 0.50 g.

C.4 Performance Requirements. Using the coordinate system specified in section C.3.7, values for the understeer gradient shall be positive for values of ground plane lateral acceleration values from 0.10 g to 0.50 g. Negative understeer gradients (oversteer) shall not be exhibited by the vehicle in the lateral acceleration range specified.

D. Occupant Retention System

<u>CPSC staff recommends that the following section, *Seat Belt Reminder System*, that requires seat belt use when using the ROV at speeds over 15 mph, replace section 11.2 *Seat Belt Reminder* in ANSI/ROHVA 1-2011.</u>

D.1 Seat Belt Reminder System. Manufacturers shall provide a seat belt reminder system that limits the maximum speed capability of the vehicle if the driver's seat belt and any occupied front passenger seat belt is not buckled. Visible feedback shall inform the driver that vehicle speed is limited until the seat belts of occupied seats are buckled.

D.1.1 Test Condition 1. Test conditions shall be as follows:

(1) ROV test weight shall be the vehicle curb weight with the test operator only. If the test operator weighs less than 98 kg (215 lbs), then the difference in weight shall be added to the vehicle to reflect an operator weight of 98 kg (215 lbs).
(2) Tires shall be inflated to the pressures recommended by the ROV manufacturer for the vehicle test weight.
(3) The test surface shall be clean, dry, smooth asphalt or concrete of less than a 1 degree (1.7%) grade.
(4) The driver's seat belt of the OEM vehicle shall not be buckled; however, the driver shall be restrained by a redundant restraint system for test safety purposes.

D.1.2 Test Condition 2. Test conditions shall be as follows:

(1) ROV test weight shall be the vehicle curb weight with the test operator and test weight in the front passenger seat only. If the test operator weighs less than 98 kg (215 lbs), then the difference in weight shall be added to the vehicle to reflect an operator weight of 98 kg (215 lbs). The passenger seat test weight shall be heavy enough to activate the passenger presence sensor.
(2) Tires shall be inflated to the pressures recommended by the ROV manufacturer for the vehicle test weight.
(3) The test surface shall be clean, dry, smooth asphalt or concrete of less than a 1 degree (1.7%) grade.
(4) The driver's seat belt shall be buckled. The passenger's seat belt shall not be buckled.

D.1.3 Test Procedure. Measure the maximum speed capability of the ROV under Test Condition 1 specified in D.1.1 and Test Condition 2 specified in D.1.2 using a radar gun or equivalent method. The test operator shall accelerate the ROV until maximum speed is reached, and shall maintain maximum speed for at least 15 m (50 ft). Speed measurement shall be made when the ROV has reached a stabilized maximum speed. A maximum speed capability test shall consist of a minimum of two measurement test runs conducted over the same track, one each in opposite directions. If more than two measurement runs are made there shall be an equal number of runs in each direction. The maximum speed capability of the ROV shall be the arithmetic average (mean) of the measurements made. A reasonable number of preliminary runs may be made prior to conducting a recorded test.

D.1.4 Maximum Speed-Limited Capability Requirement. The maximum speed capability of a vehicle with an unbuckled seat belt of the driver or any occupied front passenger seat shall be 15 mph or less.

CPSC staff recommends that the following section, *Occupant Retention Zone*, that requires a shoulder/hip zone be tested using a probe, replace section 11.3.1.2 *Zone 2- Shoulder/Hip* in ANSI/ROHVA 1-2011. CPSC staff also recommends that section 11.3.1.3 *Zone 3 – Arm/Hand* be tested using only method (A) Construction-Based Method.

D.2 Occupant Retention System Zone. Each vehicle shall restrict occupant egress and excursion for each zone through passive vehicle features.

D.2.1 General Test Conditions.

(1) Probes shall be allowed to rotate through a universal joint.
(2) Forces shall be quasi-statically applied and held for an additional 10 seconds.

D.2.2 Shoulder/Hip Zone. Retention requirements for Zone 2 shall be met by a passive barrier or structure or single-hand single-operation barrier or structure, approximately represented by the dashed lines in Figure 2, meeting the performance requirements of D.2.2.1. Such a barrier shall encompass point R when viewed from the side of the vehicle as shown in Figure 2. All measurements for the point shall be taken with respect to the base of the seatback. The base of the seatback lies on the surface of the seat base along the centerline of the seating position and is measured without simulated occupant weight on the seat. Point R is located 432 mm (17 inches) along the seatback above the base of the seatback. The point is 152 mm (6 inches) forward of and perpendicular to the seatback surface as shown in the figure. For an adjustable seat, Point R is determined with the seat adjusted to the rear-most position. Point R2 applies to an adjustable seat and is located in the same manner as Point R except that the seat is located in the forward-most position.

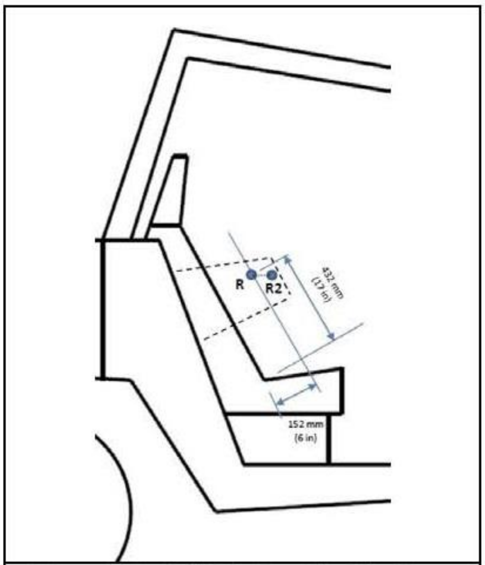


Figure 2. Point R in Shoulder/Hip Zone

D.2.2.1 Shoulder/Hip Performance Requirements. A barrier for the Shoulder/Hip zone shall be capable of withstanding a horizontal, outward force of 725 N (163 lbf). The force shall be applied through the upper arm probe shown in Figure 3. The upper arm probe shall be oriented so that Point Q on the probe is coincident with Point R for a vehicle with a fixed seat or Point Q shall be coincident with Point R2 for a vehicle with an adjustable seat. The probe's major axis shall be parallel to the seatback angle at a point 17 inches along the seat back above the base of the seatback. There shall be no deflection greater than 25 mm (1 in) upon application and removal of the force.

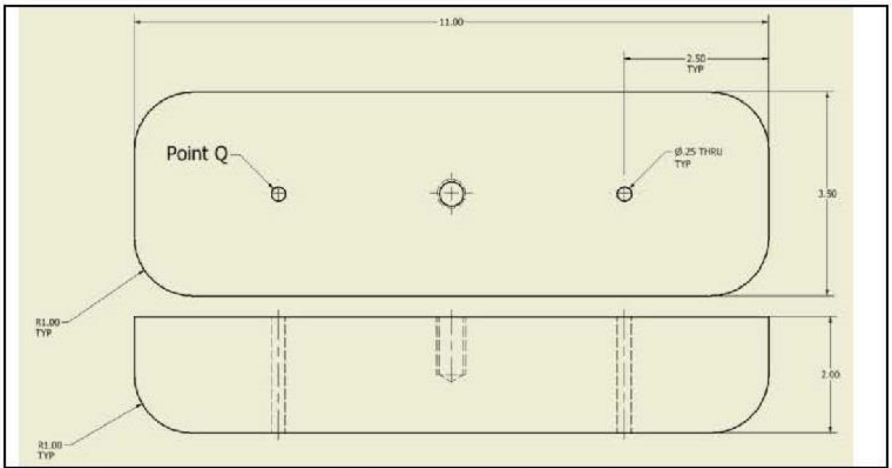


Figure 3. Shoulder/Hip Zone Probe

Appendix B: Summary of Incident Data and Hazard Characteristics

Reported Incidents

CPSC staff reviewed 428 ROV-related incidents from the Injury and Potential Injury Incident (IPII) and In-Depth Investigation (INDP) databases occurring between January 1, 2003 and December 31, 2011. From the 428 reported incidents, there were 388 injured victims and 231 fatalities. Children younger than 16 years of age made up 23 percent of the injured victims and 33 percent of the fatalities.

Of the 428 ROV-related incidents, 76 involved drivers under 16 years of age (18 percent), 227 involved adult drivers, aged 16 years or older (53 percent), and 125 involved drivers of unknown age (29 percent). Of the 227 incidents involving adult drivers, 86 (38 percent) are known to have involved the driver consuming at least one alcoholic beverage prior to the incident, 52 (23 percent) did not involve alcohol, and 89 (39 percent) have an unknown alcohol status of the driver.

Of the 619 victims who were injured or killed, most (66 percent) were in a front seat of the ROV, either as a driver or passenger, when the incidents occurred.

In many of the ROV-related incidents resulting in at least one death, CPSC staff was able to obtain more detailed information on the events surrounding the incident through an in-depth investigation (IDI). Of the 428 ROV-related incidents, 224 involved at least one death. This includes 218 incidents resulting in one fatality, 5 incidents resulting in two fatalities, and 1 incident resulting in three fatalities for a total of 231 fatalities.

Of the 224 fatal incidents, 145 (65 percent) did not occur on a paved surface, 38 (17 percent) did occur on a paved surfaced, and 41 (18 percent) occurred on unknown terrain surface.

Hazard Characteristics

CPSC staff considered incident characteristics that related to the design of the vehicle.

Lateral Rollover

Of the 428 reported ROV-related incidents, 291 (68 percent) involved lateral rollover of the vehicle. More than half of these lateral rollover incidents occurred while the vehicle was in a turn (52 percent). Of the 224 fatal incidents, 147 (66 percent) involved lateral rollover of the vehicle and 56 of those incidents (38 percent) occurred on flat terrain.

Occupant Ejection and Seat Belt Use

From the 428 ROV-related incidents reviewed by CPSC staff, 817 victims were reported to be in or on the ROV during the incident and 610 (75 percent) were known to have been injured or killed. Of the 610 fatal and non-fatal victims that were known to be in or on the ROV at the time of the incident, 433 (73 percent) were known to have been partially or fully ejected from the ROV and 269 (62 percent) of these victims were hit by a part of the vehicle, such as the roll cage or side of the ROV. In addition, of these 610 victims, seat belt use is known for 477 victims and 348 (73 percent) were not wearing a seat belt at the time of the incident.

Of the 231 reported fatalities, 225 victims from 224 incidents were in or on the vehicle at the time of the incident. Twenty-seven percent of these fatal incidents (61 out of 224) involved drivers younger than 16 years of age. 194 (86 percent of the 225 victims in or on the vehicle) were ejected partially or fully from the vehicle. Of these 194 ejected victims, 141 (73 percent) were not wearing a seat belt, 14 (7 percent) were wearing seat belts, and 39 (20 percent) have an unknown seatbelt use status.

National Electronic Injury Surveillance System (NEISS)

A total of 2,018 injuries that were related to all-terrain vehicles (ATVs) or utility vehicles were recorded in the National Electronic Injury Surveillance System (NEISS) between January 1, 2010 and August 31, 2010. For each injury, a survey was attempted to obtain further information on the vehicle involved, the victim, and the characteristics of the incident.

A total of 688 surveys were completed, resulting in a 33 percent response rate for this survey. Of the 688 completed surveys, 17 were identified as involving an ROV due to the make and model of the vehicle involved. It is possible that more cases involved an ROV but were unable to be identified due to lack of information on the vehicle make and model.

The estimated number of emergency department-treated ROV-related injuries occurring in the U.S. between January 1, 2010 and August 31, 2010 is 2,300 injuries. Extrapolating for the year 2010, the estimated number of emergency department-treated ROV-related injuries is 3,200 with a corresponding 95 percent confidence interval of 1,300 to 5,100.

7. ATTACHMENT 1: Crashlab Special Report SR2013/004, Quad Bike Performance Project: Dynamic Vehicle Performance Testing

Crashlab Special Report SR2013/004, Quad Bike Performance Project: Dynamic Vehicle Performance Testing, and Appendices A, B, C, D, E, F.

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

Crashlab®
THE SAFE DECISION

Our Ref: S/07514

Special Report SR2013/004

Quad bike performance project
Dynamic vehicle performance 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 – Dynamic handling

Test Specification: Work as directed by TARS, based upon Quad bike performance project

- Quad bike – Steady state circular driving behaviour test method
- Quad bike – Lateral transient response test method
- Quad bike – Bump obstacle test method

Tests: 546 Tests (G130368 to G131002)

Date of Tests: 14th August 2013 to 17th December 2013

Prepared by: ______________________ Date: 11 JUL 14

Drew Sherry, BE (Mech)
Test Engineer

Checked & Issued By: ______________________ Date: 11 JUL 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 dynamic vehicle performance characteristics of a number of commercially available quad bikes and side-by-side vehicles.

The test program consisted of three different dynamic tests;

- Steady-state circular driving behaviour
- Lateral transient response
- Bump obstacle perturbation

The Steady-state circular driving behaviour test consisted of slowing accelerating each vehicle from rest whilst tracking around a circle of 7.6m radius. The vehicle was accelerated until one of four outcomes occurred; it lifted the two inside tyres off the ground and tipped up, drove out of the circle, spun into the circle or could not travel any faster.

The Lateral transient response test consisted of driving the vehicle in a straight line and then rapidly inputting a steering response and maintaining the steering angle. The time taken for the vehicle to respond to the steering input of the rider and reach a constant lateral acceleration was recorded.

The Bump obstacle perturbation test consisted of towing the vehicle in straight line towards a 150mm high semi-circular 'bump' object lined up with either the right or left vehicle track. The vehicle was permitted to 'free-wheel' over the obstacle without being pulled the tow system. An Anthropomorphic Test Device (ATD) was positioned on the vehicle with the pelvis acceleration data recorded.

The Steady-state circular driving behaviour and Lateral transient response tests were conducted at Sydney Dragway, Eastern Creek, NSW Australia.

The bump obstacle perturbation tests were conducted at Crashlab, Huntingwood, NSW, Australia.

The tests described in this report were conducted between the 14th of August and the 17th of December 2013 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 with a seat that is straddled by the operator and is fitted with handle bars for steering control.

Side by Side Vehicle (SSV): A four wheeled motorised vehicle with conventional bucket seats or a 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.

1.3 Program Objectives

The objectives of the Quad bike performance project (Dynamic vehicle performance) test program were;

For the Steady state circular driving behaviour test:

- Determine the *vehicle behavioural characteristic* at the limit of lateral acceleration when accelerating from rest whilst tracking a constant radius circle for a number of commercially available Quad bikes and SSVs in a number of different operational load configurations
- Determine the *limit of lateral acceleration* whilst tracking a constant radius circle for a number of commercially available Quad bikes and SSVs in a number of different operational load configurations
- Determine the *understeer/oversteer characteristics* whilst tracking a constant radius circle for a number of commercially available Quad bikes and SSVs in a number of different operational load configurations

For the Lateral transient response test:

- Determine the s*teering response time* after a steering input for a number of commercially available Quad bikes and SSVs in a number of different operational load configurations

For the Bump obstacle perturbation test:

- Determine the *resultant pelvis acceleration* of an operator when passing over an obstacle with one wheel track for a number of commercially available Quad bikes

2 Method

2.1 Test method – Steady-state circular driving behaviour

The steady state circular driving behaviour test is based on the test specification provided by TARS. The test specification is located in Appendix A.

The steady state circular driving behaviour test was conducted by an operator slowly accelerating the vehicle from rest. The steering input was corrected by the operator so that the vehicle would track around a circle of 7.6m radius. The vehicle was accelerated continuously until one of the following dynamic vehicle behavioural characteristics occurred:

- The vehicle tipped up, lifting both inside wheels off the ground
- The vehicle drove out of the circle (understeered out of the circle)
- The vehicle spun into the circle (oversteered into the circle)
- The vehicle could not accelerate any more/ travel any faster. This may be due to the drive wheels breaking traction or the engine having insufficient power

The vehicles were tested by following the circular path in both anti-clockwise (left) and clockwise (right) directions.

All vehicles were fitted with outriggers to stop the vehicles from rolling over if the wheels lifted off the ground during the test. Photographs of vehicles fitted with outriggers are contained in Appendix F.

The vehicles were 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 103kg. The additional 103kg was made up by the mass of the operator and protective clothing, data acquisition system and outriggers. The nominal mass of the operator including protective clothing was 75kg. If the resultant total test mass was greater than required, mass was removed from the vehicle to compensate.

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

The vehicles were tested with the drive train in the most 'open' configuration. If two-wheel-drive or four-wheel-drive was selectable, the vehicle was tested in two-wheel-drive. If differentials could be locked or unlocked, they were tested in the unlocked condition.

For quad bikes the vehicle operator was seated on the saddle seat with their pelvis aligned longitudinally with the position marked for a 95th%ile ATD seated with a vertical back angle. The operator pelvis was not moved during the test and the minimum upper body movement to remain seated on the quad bike was applied. This operator state was to simulate an inert rider with no active riding input.

For side by side vehicles the operator was seated in the driver seat with the seat belt fastened. If the seat was adjustable it was placed in the rearmost position.

The following data was recorded for the duration of the test:

- Lateral acceleration (g)
- Vehicle velocity (km/h)
- Height of outrigger (left and right) from ground (mm) – used to calculate vehicle roll angle

- Steering angle (degrees - average road wheel angle)

The following information was reported for each test configuration:

- Dynamic vehicle behavioural characteristic at limit of lateral acceleration
- Lateral acceleration (g) at limit of lateral acceleration (the point at which the dynamic vehicle behavioural characteristic occurs)
- Vehicle velocity (km/h) at limit of lateral acceleration
- Steering angle vs lateral acceleration plot for duration of test (understeer/oversteer gradient plot)

A trend line was applied to the understeer/oversteer gradient plots using the procedure provided by TARS. The procedure is located in Appendix A. The gradient of the trend line and inflexion point values for each test are reported in Appendix C.

Figure 1 – steady state circular driving behaviour test in progress

Film snapshots of a steady state circular driving behaviour test are located in Appendix F.

2.2 Test method – Lateral transient response

The lateral transient response test is based on the test specification provided by TARS. The test specification is located in Appendix A.

The lateral transient response test was conducted by an operator driving the vehicle in a straight line at a velocity of 20km/h and then rapidly inputting a steering response required to generate a steady-state lateral acceleration of 0.4g. The steering input and velocity were held constant for a minimum of 360° vehicle revolution, at which point the vehicle was brought to a stop.

The vehicles were tested with both left and right steering inputs.

All vehicles were fitted with outriggers to stop the vehicles from rolling over if the wheels lifted off the ground during the test. Photographs of vehicles fitted with outriggers are contained in Appendix F.

The vehicles were tested at a mass equal to the vehicle unladen mass, plus 103kg. This additional mass was made up by the mass of the operator and protective clothing, data acquisition system and outriggers.

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

The vehicles were tested with the drive train in the most 'open' configuration. If two-wheel-drive or four-wheel-drive was selectable, the vehicle was tested in two-wheel-drive. If differentials could be locked or unlocked, they were tested in the unlocked condition.

For quad bikes the vehicle operator was seated on the saddle seat with their pelvis aligned longitudinally with the position marked for a 95^{th}%ile ATD seated with a vertical back angle. The operator pelvis was not moved during the test and the minimum upper body movement to remain seated on the quad bike was applied. This operator state was to simulate an inert rider with no active riding input.

For side by side vehicles the operator was seated in the driver seat with the seat belt fastened. If the seat was adjustable it was placed in the rearmost position.

The following data was recorded for the duration of the test:

- Lateral acceleration (g)
- Vehicle velocity (km/h)
- Yaw rate (degrees/s)
- Height of outrigger (left and right) from ground (mm) – used to calculate vehicle roll angle
- Steering angle (degrees, average road wheel angle)

The following information was reported for each test configuration:

- Lateral transient steering response time (s)

Film snapshots of a lateral transient response test are located in Appendix F.

2.3 Test method – Bump obstacle perturbation

The Bump obstacle perturbation test is based on the test specification provided by TARS. The test specification is located in Appendix A.

The Bump obstacle perturbation test was conducted by towing the vehicle in a straight line towards a 150mm high semi-circular 'bump' object which was lined up with either the left or right vehicle track. The application of towing force was discontinued before the vehicle impacted the bump such that the vehicle 'free-wheeled' over the obstacle without being under the effect of the tow system. After the vehicle had passed over the bump it was arrested to a stop.

The vehicles were tested by impacting both left and right wheel tracks with the bump obstacle individually.

An Anthropomorphic Test Device (ATD) was positioned on the vehicle saddle with the hands firmly fixed to the hands grips and the elbows bent at 10 degrees. The ATD pelvis was positioned longitudinally to achieve a vertical back angle and the feet were placed on the foot pegs.

All quad bikes that were rated for adult use were tested with a Hybrid III 95^{th} percentile Anthropomorphic Test Device (ATD) seated in the operator position. The ATD weighed 101kg, with 2kg allowed for restraint and tether straps. The ATD was clothed in form fitting cotton stretch garments (pink in colour) with short sleeves and pants that did not cover the dummy's knees, and shoes equivalent to those specified in MIL-S13192 rev P.

One vehicle tested was a youth model (Can-Am DS90X) which was rated to a maximum 70kg operator mass. This vehicle was tested with a Hybrid III 5^{th} percentile Anthropomorphic Test Device (ATD) seated in the operator position. The ATD weighed 49kg with 2kg allowed for restraint and tether straps. The ATD was clothed in form fitting cotton stretch garments (pink in colour) with short sleeves and pants that did not cover the dummy's knees, and shoes equivalent to those specified in MIL-S13192 rev P.

Photographs of vehicles set up for testing are contained in Appendix F.

The vehicles were tested at a mass equal to the vehicle unladen mass, plus 103kg (51kg for the youth model vehicle). To account for the mass of the data acquisition system, an equal mass was removed from the vehicle.

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

The vehicles were tested with the drive train in the most 'open' configuration. If two-wheel-drive or four-wheel-drive was selectable, the vehicle was tested in two-wheel-drive. If differentials could be locked or unlocked, they were tested in the unlocked condition. The vehicle engine was not running during the tests.

The following data was recorded for the duration of the test:

- ATD pelvis lateral acceleration (g)
- ATD pelvis vertical acceleration (g)
- Vehicle velocity (km/h)

The following information was reported for each test configuration:

- ATD peak resultant (lateral/vertical) pelvis acceleration (g)

Quad bikes were subjected to the bump obstacle perturbation test, SSVs were not.

Figure 2 – bump obstacle perturbation test in progress

Film snapshots of a bump obstacle perturbation test are located in Appendix F.

2.4 Test vehicles

The test program encompassed sixteen vehicles, which can be separated into three broad vehicle types.

Eight of the vehicles were agricultural focussed work quad bikes (agricultural quads) fitted with front and rear load racks:

- Honda Fourtrax TRX250
- Honda Foreman TRX500FM
- Yamaha Grizzly YFM450FAP
- Polaris Sportsman 450HO
- Suzuki Kingquad 400ASI
- Kawasaki KVF300
- Kymco MXU300
- CF Moto CF500

Three of the vehicles were recreational style quad bikes (recreational quads), without load racks:

- Can-Am DS90X
- Yamaha Raptor YFM250R
- Honda TRX700XX

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

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

Vehicle details are contained in Appendix E, vehicle photographs are contained in Appendix F.

2.5 Test surfaces

The steady state circular driving behaviour tests and lateral transient response tests were conducted at Sydney Dragway, Eastern Creek, NSW. All vehicles were tested on the asphalt car park surface. This surface is flat, smooth and level with a slope of 0.2° and a crossfall of 0.6°. The surface friction was tested with a vehicle fitted with a Vericom VC4000DAQ unit and found to have an average coefficient of friction of 0.76.

A number of vehicles were also tested on a mowed grass surface. This surface was flat and level with small undulations typical of a grass surface.

Photographs of both surfaces are located in Appendix F.

2.6 Cargo load

A number of vehicles were tested with a cargo load applied to each of the nominated cargo areas for the steady state circular driving behaviour tests and lateral transient response tests.

The load racks or load trays were loaded to their maximum manufacturer rated capacity. If the total mass of the rider and cargo load exceeded the maximum manufacturer rated vehicle load, the cargo load was reduced and distributed between the load areas as a ratio of the individual load rack capacities.

The cargo load consisted of sand bags filled with dry sand. Sand bags were selected as they provided a flexible load configuration with a relatively low centre of gravity. This represented a 'best case scenario' in testing when compared to most real world load conditions. The load was distributed evenly across the load area. The sand bags were restrained with webbing straps and sandwiched between thin sheets of ply wood to prevent the bags falling through the load rack or moving during the tests. The mass of the ply wood and straps were accounted for in the cargo load.

2.7 Crush Protection Devices (CPDs)

Two Crush Protection Devices (CPDs) were including in the test series to determine their effect on dynamic handling. Details of the devices are included in Appendix E.

Each of the CPDs was fitted to one of the quad bikes (Honda TRX250). The quad bike was selected to represent a typical median result with respect to static rollover performance.

2.8 Test matrix

The test matrix consisted of 546 individual tests as tabled below.
The Steady-state circular driving behaviour and Lateral transient response tests were conducted with 40 different vehicle configurations and the Bump obstacle perturbation tests were conducted with 11 different vehicle configurations. Each vehicle configuration was tested three times in both the left and right vehicle direction.

				Steady-state circular driving behaviour		Lateral transient response		Bump obstacle perturbation	
Vehicle make	Vehicle model	Surface	Additional Conditions	Left	Right	Left	Right	Left	Right
Honda	TRX250	Asphalt	-	3	3	3	3	3	3
Honda	TRX500FM	Asphalt	-	3	3	3	3	3	3
Yamaha	YFM450FAP Grizzly	Asphalt	-	3	3	3	3	3	3
Polaris	Sportsman 450HO	Asphalt	-	3	3	3	3	3	3
Suzuki	Kingquad 400ASI	Asphalt	-	3	3	3	3	3	3
Kawasaki	KVF300	Asphalt	-	3	3	3	3	3	3
Kymco	MXU300	Asphalt	-	3	3	3	3	3	3
CF Moto	CF500	Asphalt	-	3	3	3	3	3	3
Yamaha	Rhino 700	Asphalt	-	3	3	3	3		
Kubota	RTV500	Asphalt	-	3	3	3	3		
John Deere	Gator XUV825i	Asphalt	-	3	3	3	3		
Honda	Big red MUV700	Asphalt	-	3	3	3	3		
Tomcar	TM2	Asphalt	-	3	3	3	3		
Can-am	DS90X	Asphalt	-	3	3	3	3	3	3
Honda	TRX700XX	Asphalt	-	3	3	3	3	3	3
Yamaha	YFM250R Raptor	Asphalt	-	3	3	3	3	3	3
Honda	TRX250	Asphalt	Front load	3	3	3	3		
Honda	TRX250	Asphalt	Rear load	3	3	3	3		
Honda	TRX250	Asphalt	Front & rear load	3	3	3	3		
Honda	TRX250	Grass	-	3	3	3	3		
Honda	TRX250	Grass	Front load	3	3	3	3		
Honda	TRX250	Grass	Rear load	3	3	3	3		
Honda	TRX250	Grass	Front & rear load	3	3	3	3		
Honda	TRX250	Asphalt	Quadbar CPD	3	3	3	3		
Honda	TRX250	Asphalt	Lifeguard CPD	3	3	3	3		
Honda	TRX250	Asphalt	Active riding, sideways	3	3	3	3		
Honda	TRX250	Asphalt	Active riding, forwards	3	3	3	3		
Honda	TRX250	Asphalt	Active riding, rearwards	3	3	3	3		
Honda	TRX250	Asphalt	Higher tyre pressures	3	3	3	3		
Honda	TRX250	Asphalt	Alternate rider	3	3	3	3		
Yamaha	YFM450FAP Grizzly	Grass	-	3	3	3	3		
Yamaha	YFM250R Raptor	Grass	-	3	3	3	3		
Kawasaki	KVF300	Asphalt	Alternate rider	3	3	3	3		
Honda	Big red MUV700	Asphalt	Rear differential locked	3	3	3	3		
Honda	Big red MUV700	Asphalt	Rear load	3	3	3	3		
Honda	Big red MUV700	Grass	-	3	3	3	3		
Honda	Big red MUV700	Grass	Rear load	3	3	3	3		
Yamaha	Rhino 700	Asphalt	Rear load	3	3	3	3		
Yamaha	Rhino 700	Grass	-	3	3	3	3		
Yamaha	Rhino 700	Grass	Rear load	3	3	3	3		

Steady-state circular driving behaviour total	240
Lateral transient response total	240
Bump obstacle perturbation total	66
Total	**546**

Table 1- Test Matrix

For the full test matrix with test run numbers see Appendix B.

2.9 Instrumentation and data acquisition

For the Steady state circular driving behaviour tests and Lateral transient response tests the vehicles were fitted with an AiM EVO4 data acquisition unit which was mounted close to the vehicle centre of gravity. This data acquisition system has an internal tri-axial accelerometer and was configured to record external instruments measuring yaw rate, steering angle, vehicle velocity via GPS and vertical distance to ground on the vehicle's left and right side. The acquisition rate was 100Hz. The vehicles were also fitted with an under-body camera to record the point of wheel lift on the Steady state circular driving behaviour tests.

For the Bump obstacle perturbation tests the vehicles were fitted with an AiM EVO4 data acquisition unit and a DTS Slice data acquisition unit which were mounted to the rear of the vehicles, just behind the operator seat. The AiM EVO4 was equipped with an internal tri-axial accelerometer and was configured to record external instruments which measured yaw rate, vehicle velocity via GPS and vertical distance to ground on the vehicle's left and right side. The acquisition rate was 100Hz. The DTS Slice was configured to record vertical, lateral and longitudinal ATD pelvis acceleration at an acquisition rate of 10000Hz.

Diadem software was used for data analysis and reporting.

Photographs of instrument installation are contained in Appendix F, details of the instruments are contained in Appendix G.

3 Test Results

Table 2 – Test results summary - Steady-state circular driving behaviour

					Steady-state circular driving behaviour - Average limit of lateral acceleration (g)		Steady-state circular driving behaviour - Average velocity at limit of lateral acceleration (km/h)		Dynamic vehicle characteristic at limit of lateral acceleration	
Vehicle make	Vehicle model	Specimen number	Surface	Additional Conditions	Left	Right	Left	Right	Left	Right
Honda	TRX250	TS57199	Asphalt	-	0.46	0.46	21.8	21.4	Two wheel lift	Two wheel lift
Honda	TRX500FM	TS57200	Asphalt	-	0.52	0.52	21.5	23.6	Two wheel lift	Two wheel lift
Yamaha	YFM450FAP Grizzly	TS57201	Asphalt	-	0.46	0.41	21.0	21.3	Two wheel lift	Two wheel lift
Polaris	Sportsman 450HO	TS57202	Asphalt	-	0.61	0.55	24.0	24.2	Two wheel lift	Two wheel lift
Suzuki	Kingquad 400ASI	TS57203	Asphalt	-	0.51	0.45	22.2	22.3	Two wheel lift	Two wheel lift
Kawasaki	KVF300	TS57204	Asphalt	-	0.46	0.49	21.7	21.7	Two wheel lift	Two wheel lift
Kymco	MXU300	TS57205	Asphalt	-	0.39	0.36	20.8	19.9	Two wheel lift	Two wheel lift
CF Moto	CF500	TS57206	Asphalt	-	0.50	0.55	23.3	23.8	Two wheel lift	Two wheel lift
Yamaha	Rhino 700	TS57207	Asphalt	-	0.74	0.61	28.4	25.2	Two wheel lift	Two wheel lift
Kubota	RTV500	TS57208	Asphalt	-	0.62	0.54	24.6	22.7	Inside rear wheel broke traction (limiting speed)	Inside rear wheel broke traction (limiting speed)
John Deere	Gator XUV825i	TS57209	Asphalt	-	0.61	0.54	25.6	23.8	Inside rear wheel broke traction (limiting speed)	Inside rear wheel broke traction (limiting speed)
Honda	Big red MUV700	TS57210	Asphalt	-	0.66	0.56	25.5	23.8	Inside rear wheel broke traction (limiting speed)	Inside rear wheel broke traction (limiting speed)
Tomcar	TM2	TS58278	Asphalt	-	0.52	0.49	23.3	24.0	Drove out of circle (understeered out of circle)	Drove out of circle (understeered out of circle)
Can-am	DS90X	TS57211	Asphalt	-	0.68	0.54	24.4	24.2	Two wheel lift	Two wheel lift
Yamaha	YFM250R Raptor	TS57212	Asphalt	-	0.55	0.47	22.2	23.2	Two wheel lift	Two wheel lift
Honda	TRX700XX	TS57213	Asphalt	-	0.72	0.55	24.9	25.5	Two wheel lift	Two wheel lift
Honda	TRX250	TS57199	Asphalt	Front load	0.43	0.45	21.4	21.3	Two wheel lift	Two wheel lift
Honda	TRX250	TS57199	Asphalt	Rear load	0.46	0.47	21.4	21.9	Two wheel lift	Two wheel lift
Honda	TRX250	TS57199	Asphalt	Front & rear load	0.45	0.43	21.3	20.9	Two wheel lift	Two wheel lift
Honda	TRX250	TS57199	Grass	-	0.47	0.41	21.7	21.2	Two wheel lift	Two wheel lift
Honda	TRX250	TS57199	Grass	Front load	0.45	0.38	20.2	20.7	Two wheel lift	Two wheel lift
Honda	TRX250	TS57199	Grass	Rear load	0.45	0.41	21.7	21.4	Two wheel lift	Two wheel lift
Honda	TRX250	TS57199	Grass	Front & rear load	0.43	0.40	20.9	20.7	Two wheel lift	Two wheel lift
Honda	TRX250	TS57199+CPD1	Asphalt	Quadbar CPD	0.45	0.47	22.0	21.9	Two wheel lift	Two wheel lift
Honda	TRX250	TS57199+CPD2	Asphalt	Lifeguard CPD	0.46	0.45	21.4	21.9	Two wheel lift	Two wheel lift
Honda	TRX250	TS57199	Asphalt	Active riding, sideways	0.57	0.52	22.9	23.1	Two wheel lift	Two wheel lift
Honda	TRX250	TS57199	Asphalt	Active riding, forwards	0.47	0.44	21.5	21.2	Two wheel lift	Two wheel lift
Honda	TRX250	TS57199	Asphalt	Active riding, rearwards	0.47	0.49	22.0	22.1	Two wheel lift	Two wheel lift
Honda	TRX250	TS57199	Asphalt	Higher tyre pressures	0.48	0.49	22.1	22.7	Two wheel lift	Two wheel lift
Honda	TRX250	TS57199	Asphalt	Alternative rider	N/A	0.44	N/A	22.4	Two wheel lift	Two wheel lift
Yamaha	YFM450FAP Grizzly	TS57201	Grass	-	0.46	0.43	22.1	22.0	Two wheel lift	Two wheel lift
Yamaha	YFM250R Raptor	TS57212	Grass	-	0.56	0.44	22.0	21.5	Two wheel lift	Two wheel lift
Kawasaki	KVF300	TS57204	Asphalt	Alternative rider	0.42	0.49	21.9	21.8	Two wheel lift	Two wheel lift
Honda	Big red MUV700	TS57210	Asphalt	Rear differential locked	0.75	0.67	27.0	26.9	Spun out (oversteered into circle)	Spun out (oversteered into circle)
Honda	Big red MUV700	TS57210	Asphalt	Rear load	0.62	0.55	25.2	24.7	Inside rear wheel broke traction (limiting speed)	Inside rear wheel broke traction (limiting speed)
Honda	Big red MUV700	TS57210	Grass	-	0.53	0.59	22.7	22.5	Inside rear wheel broke traction (limiting speed)	Inside rear wheel broke traction (limiting speed)
Honda	Big red MUV700	TS57210	Grass	Rear load	0.52	0.43	23.1	23.0	Drove out of circle (understeered out of circle)	Drove out of circle (understeered out of circle)
Yamaha	Rhino 700	TS57207	Asphalt	Rear load	0.74	0.68	25.9	25.2	Two wheel lift	Two wheel lift
Yamaha	Rhino 700	TS57207	Grass	-	0.66	0.56	24.8	23.4	Spun out (oversteered into circle)	Spun out (oversteered into circle)
Yamaha	Rhino 700	TS57207	Grass	Rear load	0.63	0.57	25.0	23.5	Spun out (oversteered into circle)	Spun out (oversteered into circle)

Results for each Steady-state circular driving behaviour test are located in Appendix C of this report.
Data plots of steering angle vs lateral acceleration are located in Appendix D of this report.
It should be noted that the data files for the Honda TRX250 with alternative rider in the left (anti-clockwise) direction were not able to be reported due to a data recording issue.
Results for steering gradient are located in Appendix C of this report

Table 3 – Test results summary - Lateral transient response

Vehicle make	Vehicle model	Specimen number	Surface	Additional Conditions	Average Lateral transient response time (s) Left	Right
Honda	TRX250	TS57199	Asphalt		0.12	0.14
Honda	TRX500FM	TS57200	Asphalt		0.16	0.17
Yamaha	YFM450FAP Grizzly	TS57201	Asphalt		0.14	0.13
Polaris	Sportsman 450HO	TS57202	Asphalt		0.13	0.13
Suzuki	Kingquad 400ASI	TS57203	Asphalt		0.17	0.15
Kawasaki	KVF300	TS57204	Asphalt		0.13	0.13
Kymco	MXU300	TS57205	Asphalt		0.11	0.09
CF Moto	CF500	TS57206	Asphalt		0.23	0.17
Yamaha	Rhino 700	TS57207	Asphalt		0.29	0.28
Kubota	RTV500	TS57208	Asphalt		0.18	0.20
John Deere	Gator XUV825i	TS57209	Asphalt		0.26	0.28
Honda	Big red MUV700	TS57210	Asphalt		0.25	0.28
Tomcar	TM2	TS58278	Asphalt		0.22	0.17
Can-am	DS90X	TS57211	Asphalt		0.15	0.15
Yamaha	YFM250R Raptor	TS57212	Asphalt		0.15	0.20
Honda	TRX700XX	TS57213	Asphalt		0.10	0.14
Honda	TRX250	TS57199	Asphalt	Front load	0.16	0.13
Honda	TRX250	TS57199	Asphalt	Rear load	0.21	0.20
Honda	TRX250	TS57199	Asphalt	Front & rear load	0.16	0.23
Honda	TRX250	TS57199	Grass		0.24	0.27
Honda	TRX250	TS57199	Grass	Front load	0.14	0.18
Honda	TRX250	TS57199	Grass	Rear load	0.34	0.40
Honda	TRX250	TS57199	Grass	Front & rear load	0.22	0.30
Honda	TRX250	TS57199+CPD1	Asphalt	Quadbar CPD	0.13	0.16
Honda	TRX250	TS57199+CPD2	Asphalt	Lifeguard CPD	0.15	0.16
Honda	TRX250	TS57199	Asphalt	Active riding, sideways	0.25	0.25
Honda	TRX250	TS57199	Asphalt	Active riding, forwards	0.14	0.12
Honda	TRX250	TS57199	Asphalt	Active riding, rearwards	0.18	0.18
Honda	TRX250	TS57199	Asphalt	Higher tyre pressures	0.10	0.11
Honda	TRX250	TS57199	Asphalt	Alternative rider	0.12	0.18
Yamaha	YFM450FAP Grizzly	TS57201	Grass		0.37	0.25
Yamaha	YFM250R Raptor	TS57212	Grass		0.34	0.47
Kawasaki	KVF300	TS57204	Asphalt	Alternative rider	0.14	0.14
Honda	Big red MUV700	TS57210	Asphalt	Rear differential locked	0.22	0.23
Honda	Big red MUV700	TS57210	Asphalt	Rear load	0.21	0.22
Honda	Big red MUV700	TS57210	Grass		0.47	0.37
Honda	Big red MUV700	TS57210	Grass	Rear load	0.40	0.36
Yamaha	Rhino 700	TS57207	Asphalt	Rear load	0.28	0.42
Yamaha	Rhino 700	TS57207	Grass		0.43	0.47
Yamaha	Rhino 700	TS57207	Grass	Rear load	0.35	0.48

Results for each Lateral transient response test are located in Appendix C of this report.
Data traces of each Lateral transient response test are located in Appendix D of this report

Table 4 – Test results summary - Bump obstacle perturbation

			Average resultant acceleration (g)		
Vehicle make	Vehicle model	Specimen number	Left perturbation	Right perturbation	Maximum
Honda	Fourtrax TRX250	TS57199	2.45	2.78	*2.78*
Honda	Foreman TRX500FM	TS57200	2.14	2.14	*2.14*
Yamaha	Grizzly YFM450FAP	TS57201	1.76	1.93	*1.93*
Polaris	Sportsman 450HO	TS57202	1.93	1.72	*1.93*
Suzuki	Kingquad 400ASI	TS57203	2.15	2.22	*2.22*
Kawasaki	KVF300	TS57204	2.55	2.97	*2.97*
Kymco	MXU300	TS57205	2.28	2.13	*2.28*
CF Moto	CF500	TS57206	1.57	1.80	*1.80*
Can-am	DS90X	TS57211	2.62	3.48	*3.48*
Yamaha	Raptor YFM250R	TS57212	3.15	3.11	*3.15*
Honda	TRX700XX	TS57213	1.89	2.05	*2.05*

Results for each Bump obstacle perturbation test are located in Appendix C of this report.
Data traces of each Bump obstacle perturbation test are located in Appendix D of this report

4 Discussion

4.1 Steady-state circular driving behaviour

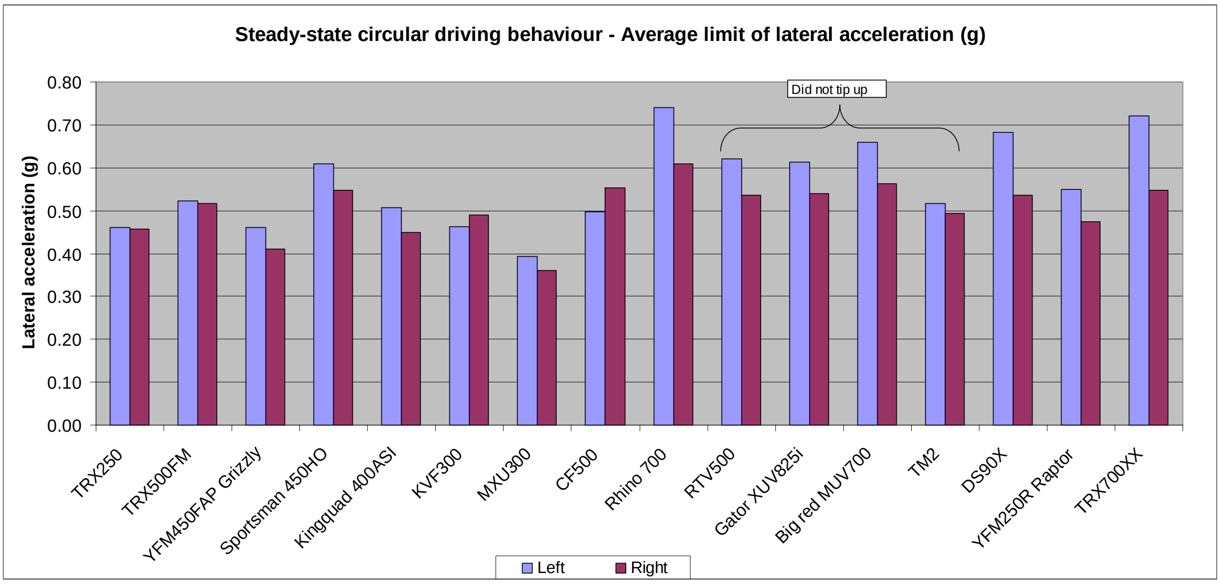


Figure 3: Results Steady-state circular driving behaviour, average limit of lateral acceleration

Four side-by-side vehicles fitted with open rear differentials did not tip up during the tests. All other vehicles tipped up between 0.36g and 0.74g lateral acceleration.

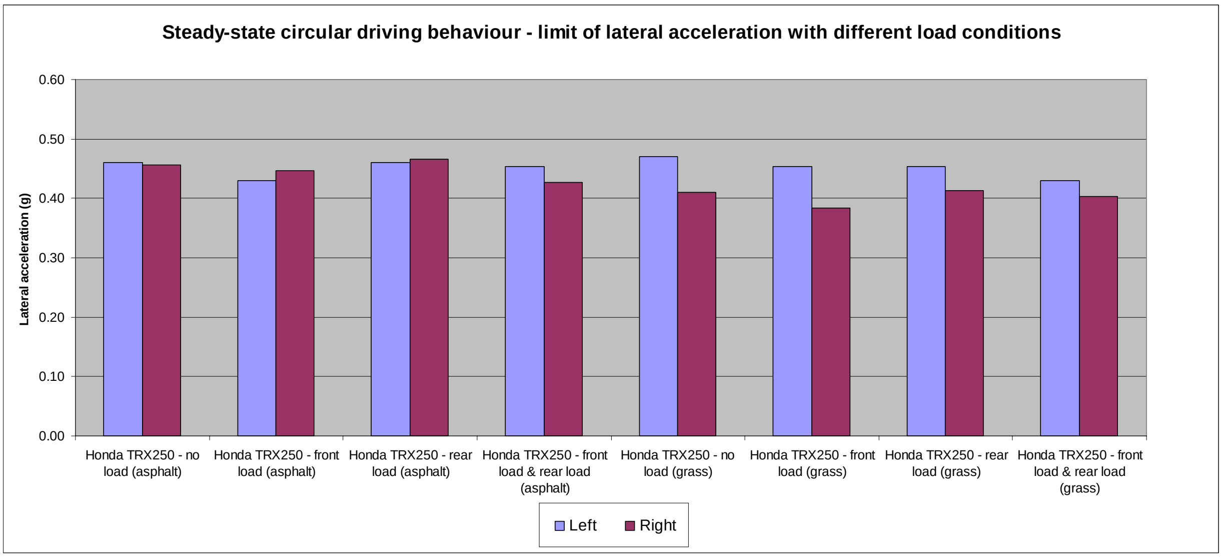


Figure 4: Results Steady-state circular driving behaviour, average limit of lateral acceleration with different load conditions and different surfaces

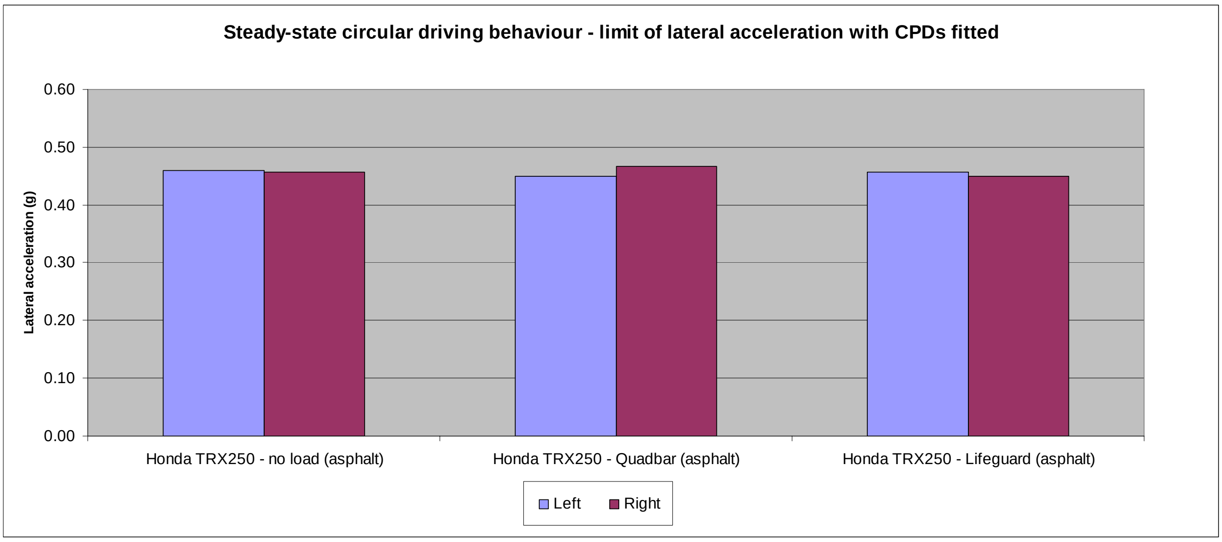


Figure 5: Results Steady-state circular driving behaviour, average limit of lateral acceleration with CPDs fitted

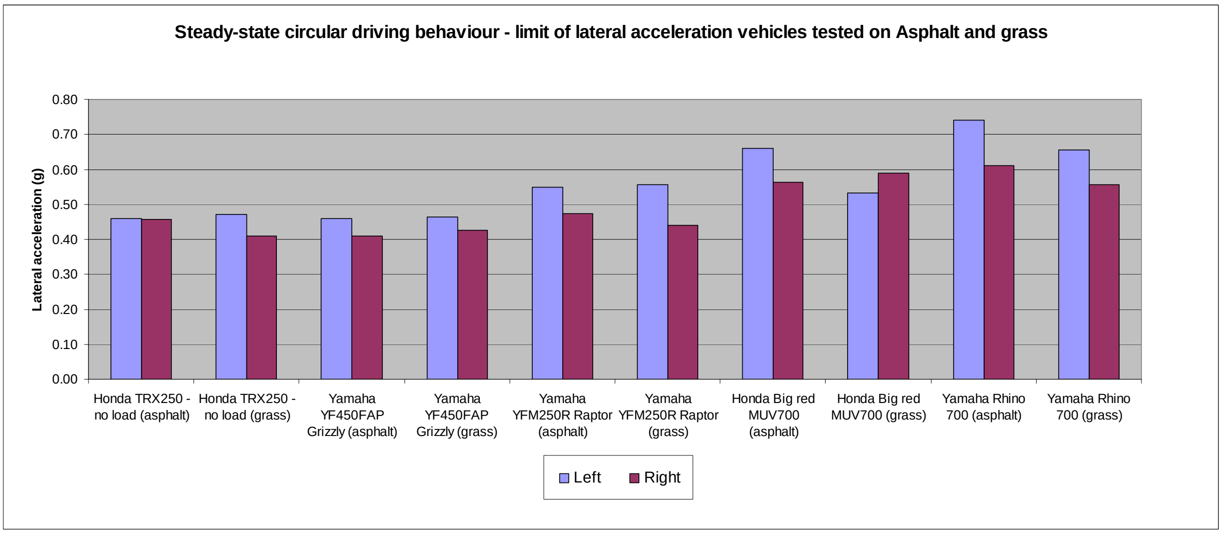


Figure 6: Results Steady-state circular driving behaviour, average limit of lateral acceleration five vehicles tested on asphalt and grass

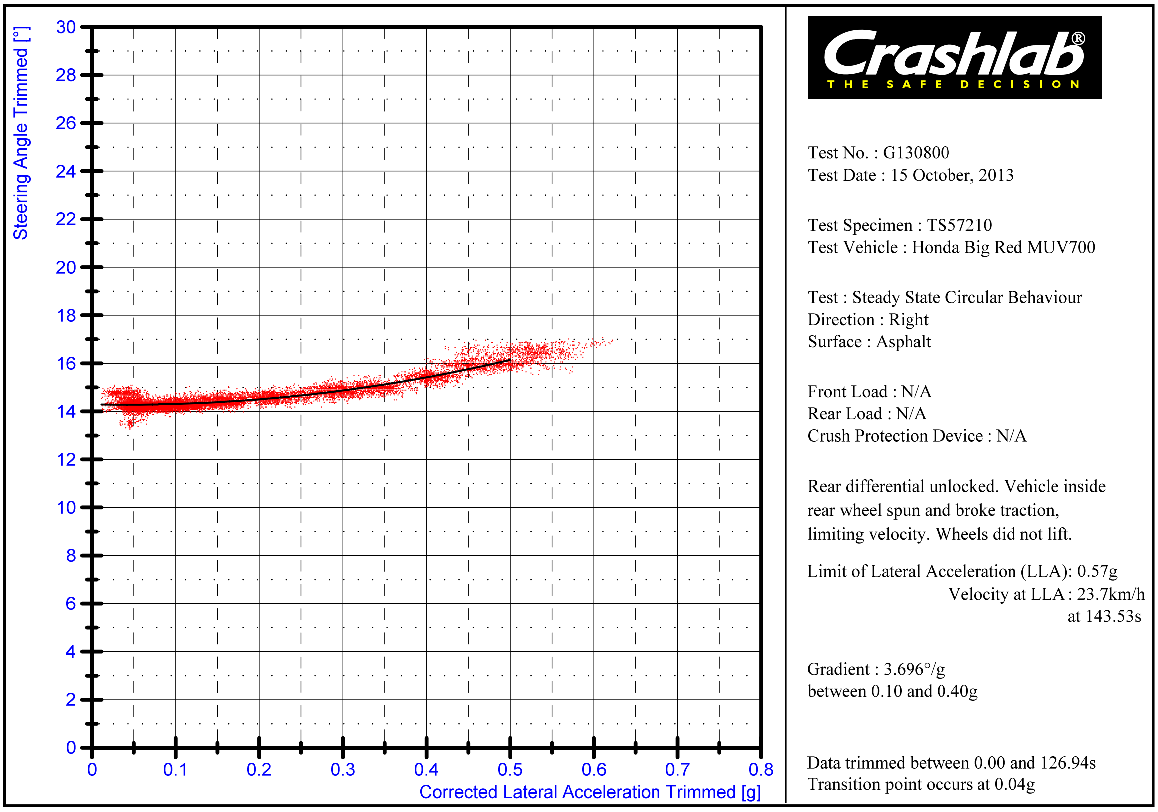


Figure 7: Steady-state circular driving behaviour, steering angle vs lateral acceleration – example of a vehicle exhibiting an understeer characteristic

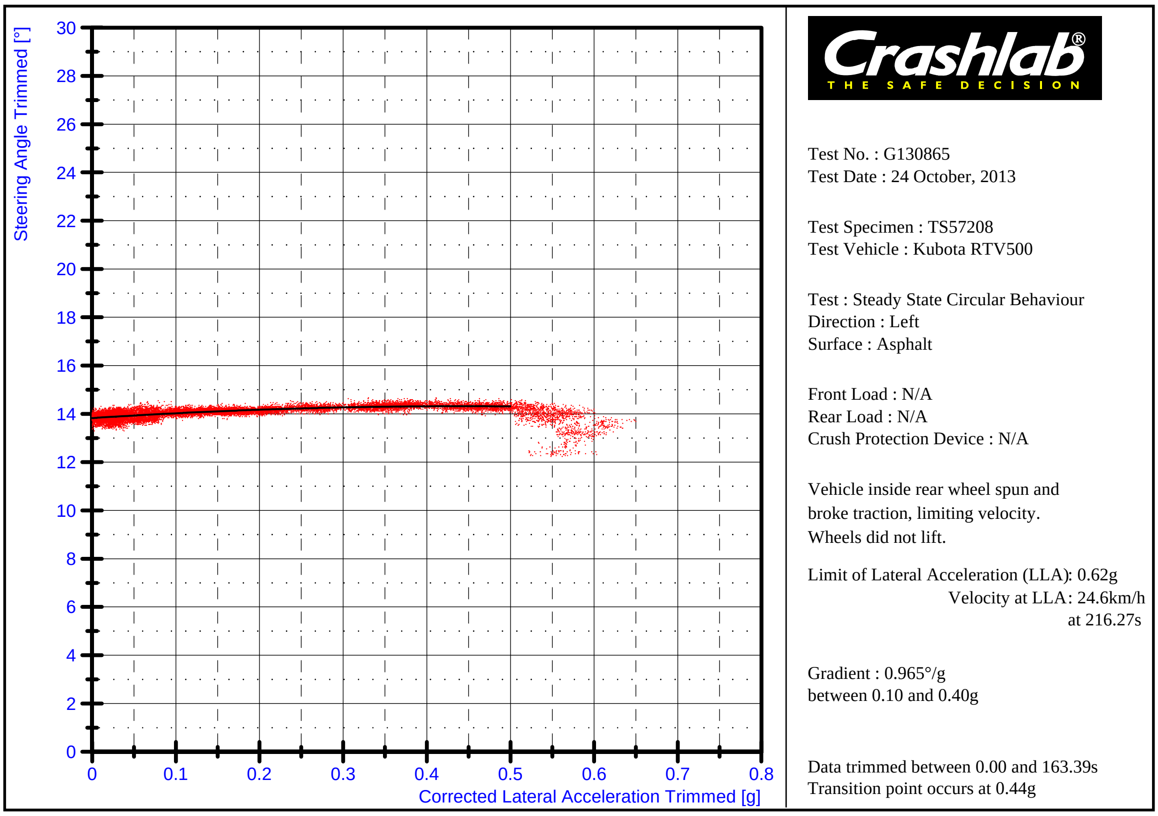


Figure 8: Steady-state circular driving behaviour, steering angle vs lateral acceleration – example of vehicle exhibiting a relatively neutral steer characteristic

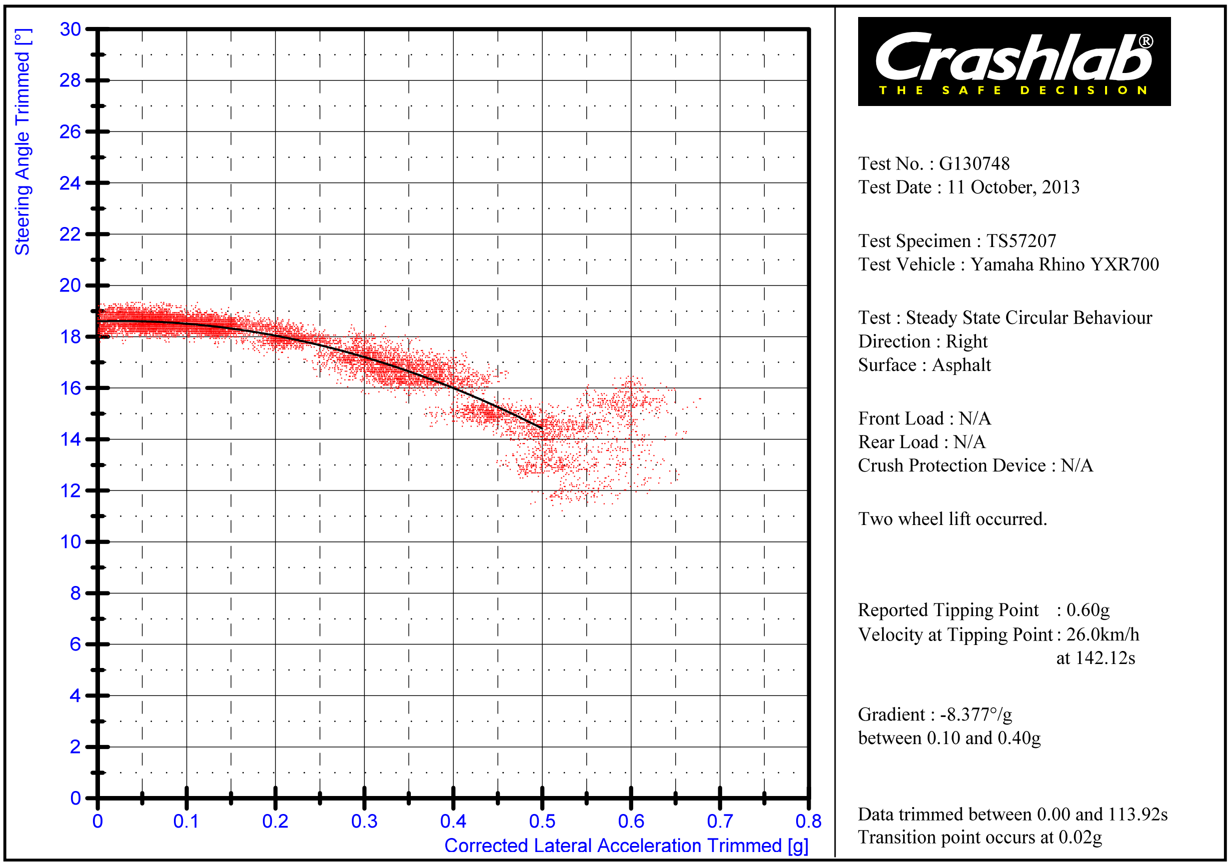


Figure 9: Steady-state circular driving behaviour, steering angle vs lateral acceleration – example of a vehicle exhibiting an oversteer characteristic

A positive steering gradient shows a vehicle that is experiencing understeer. In this situation a larger steering input is required to maintain the vehicle tracking on the prescribed course with an increase in vehicle velocity and lateral acceleration.

A negative steering gradient shows a vehicle that is experiencing oversteer. In this circumstance a smaller steering input is required to maintain the vehicle tracking on the prescribed course with an increase in vehicle velocity and lateral acceleration.

A neutral or flat steering gradient is representative of a vehicle that requires no change to the steering input to maintain the vehicle tracking on the prescribed course with an increase in vehicle velocity and lateral acceleration.

NB: Steering angle vs lateral acceleration plots display the individual data points from the test recorded at 100Hz.

For continuity of data presentation, steering angle and lateral acceleration have been presented with a positive sign convention for both left and right test directions.

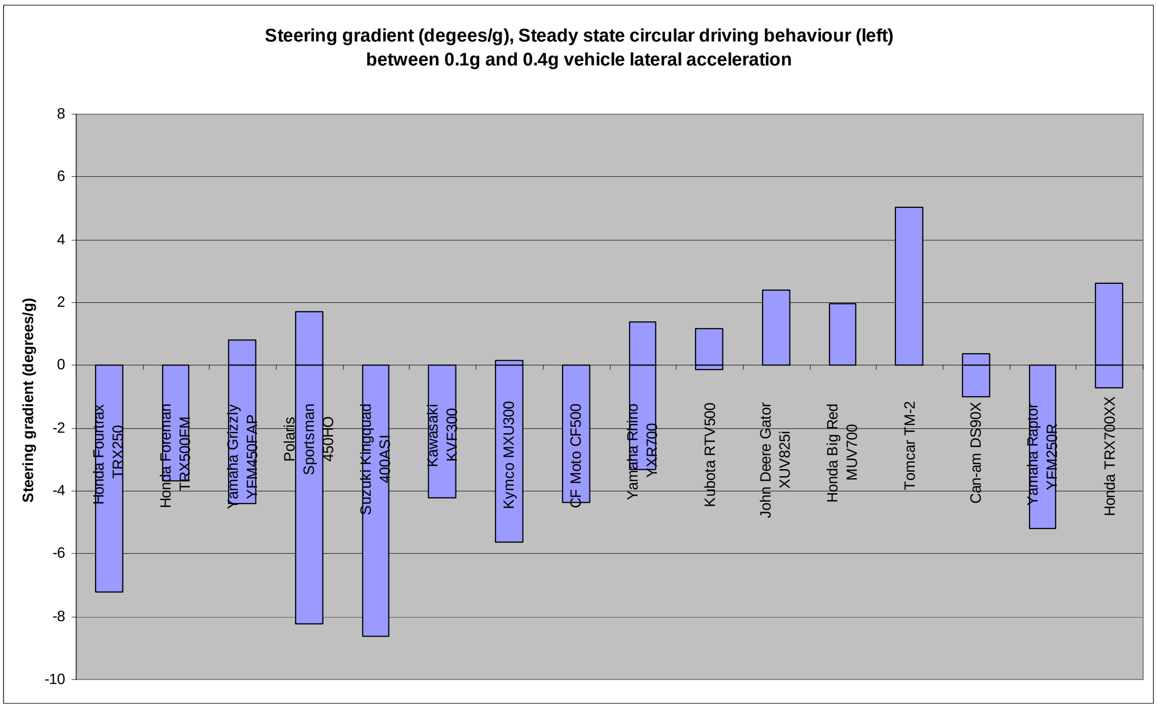


Figure 10: Average steady-state circular driving behaviour (left direction), steering gradient between 0.1g and 0.4g vehicle lateral acceleration

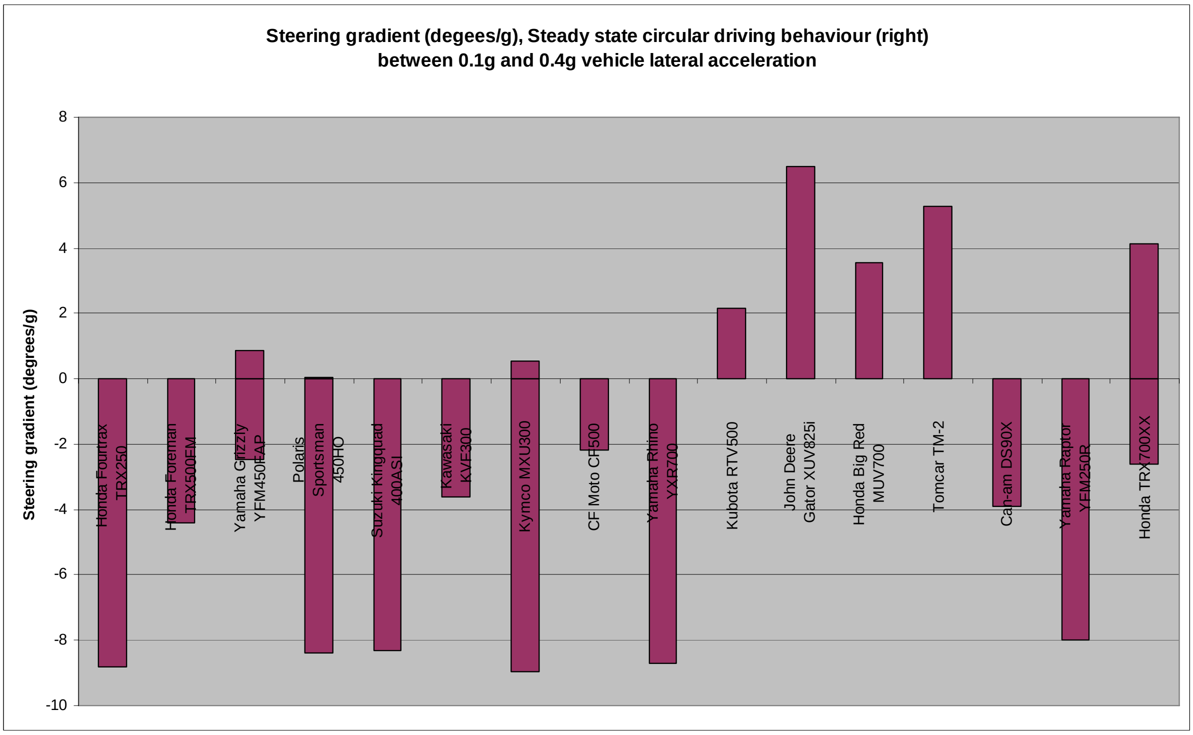


Figure 11: Average steady-state circular driving behaviour (right direction), steering gradient between 0.1g and 0.4g vehicle lateral acceleration

A positive steering gradient represents an understeer characteristic, a negative steering gradient represents an oversteer characteristic. If the bar graph covers both positive and negative steering gradients, the vehicle transitioned between understeer to oversteer during the test. For individual vehicle steering gradient characteristic plots refer to Appendix D.

4.2 Lateral transient response

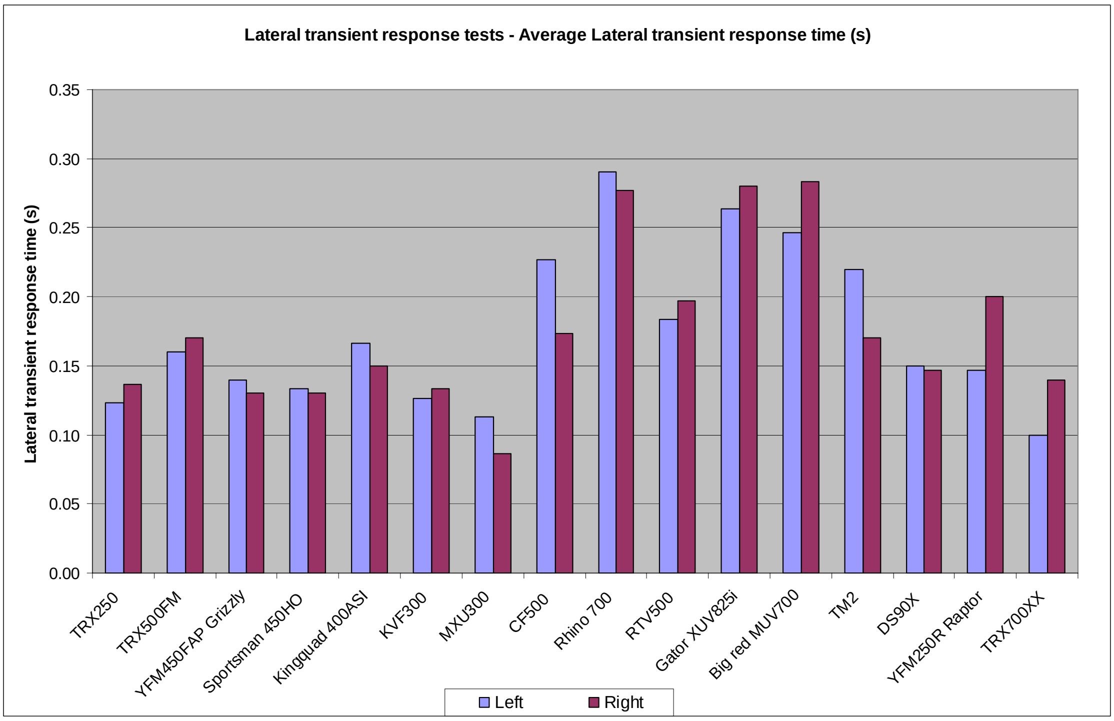


Figure 12: Results Lateral transient response test, average steering response time - unladen vehicles on asphalt

The average steering response times for all vehicles tested unladen on asphalt varied between 0.09s and 0.29s for the quickest and slowest responding vehicles. Typically the larger SSVs had a slower steering response times than the smaller quad bikes.

4.3 Bump obstacle perturbation

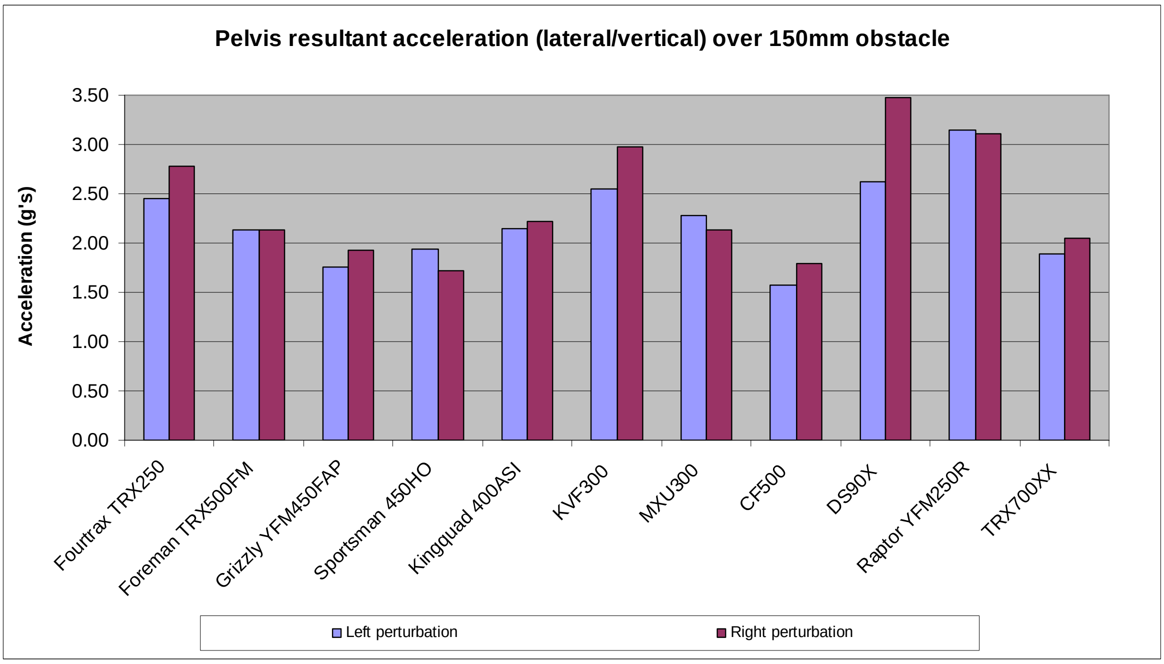


Figure 13: Results Bump obstacle perturbation, average pelvis resultant acceleration

4.4 Repeatability of results

Each test configuration was tested three times to establish result repeatability, full result tables are contained in Appendix C.

For the Steady-state circular driving behaviour tests, the dynamic vehicle behavioural characteristic was the same for each of the three tests for all configurations tested.

Due to vehicle vibration the lateral acceleration recorded for each circular driving behaviour test contained a significant amount of noise. After the noise was filtered and centre of the data spread was selected, the value for lateral acceleration at point of tip up or limit of lateral acceleration for vehicles that did not tip up, varied between repeat tests by up to 0.05g on asphalt. When the vehicles were tested on the grass surface the results typically varied by no more than 0.1g, however one test configuration with a fully laden vehicle had results that varied by 0.27g between the three tests.

The lateral transient steering response times for vehicles in the unladen test condition when tested on asphalt varied between repeat tests by less than 0.14 seconds with a significant number of tests displaying a variance of less than 0.05 seconds.
The largest variance between three repeat tests was 0.25 seconds for a vehicle tested on grass.

In the Bump obstacle perturbation tests, the lateral/vertical ATD pelvis resultant acceleration values varied by up to 0.45g between three tests of the same configuration. Typically the variation between repeat runs was less than 0.25g.

5 Conclusions

Eleven quad bikes and five side-by-side vehicles were subjected to Steady-state circular driving behaviour tests in a total of forty different configurations.

When tested on asphalt unloaded, all quad bikes tipped up at lateral acceleration values of between 0.33g and 0.73g.

One Side by Side Vehicle tipped up, one SSV understeered out of the circle and the three SSVs fitted with open centre differentials lost traction with the inside drive wheel and could not travel any faster around the circle.

The three quad bikes that were tested on asphalt and grass displayed very similar handling characteristics and tipped up at similar lateral acceleration values on both surfaces.
The SSV that tipped up on asphalt, oversteered into the circle at a lower lateral acceleration value when tested on grass.
The SSV that lost traction with its inside drive wheel (thus limiting vehicle speed) on asphalt, displayed the same characteristic on grass, however the lateral acceleration values varied by up to 0.13g.

Both understeer characteristics (positive steering gradient) and oversteer characteristics (negative steering gradient) were displayed by the vehicles tested. Typically vehicles with an open rear differential displayed an understeer characteristic and vehicles fitted with a solid or locked rear differential showed an oversteer characteristic. A number of vehicles also transitioned between understeer to oversteer during the test.

Eleven quad bikes and five side-by-side vehicles were subjected to Lateral transient response tests in a total of forty different configurations.

All vehicles tested on asphalt without a cargo load returned steering response times of less than 0.4 seconds, with a significant number of the vehicles displaying steering response times of less than 0.2 seconds.

The three quad bikes and two SSV's that were also tested on grass displayed longer lateral transient response times when tested on grass. The lateral transient response times were typically in the order of twice as long when tested on grass compared to asphalt. The average lateral transient response times on grass for these five vehicles were less than 0.5 seconds, however the slowest individual lateral transient response time for one of the SSVs was 0.61seconds.

Eleven quad bikes were subjected to the bump obstacle test.

The vehicles exhibited ATD pelvis lateral/vertical resultant acceleration values of between 1.47g and 3.66g. Quad bikes that exhibited lower resultant ATD pelvis acceleration typically showed little ATD movement relative to the seat of the quad bike. Quad bikes that exhibited higher resultant ATD pelvis acceleration typically showed significant ATD movement relative to the seat of the quad bike.

6 Reference Material

[1] ISO 2012, *Passenger cars – Steady-state circular driving behaviour – open-loop test methods,* ISO 4138:2012, ISO (International Organization for Standardization), Geneva Switzerland.

[2] ISO 2011, *Road vehicles – Lateral transient response test methods – open loop test methods,* ISO 7401:2011, ISO (International Organization for Standardization), Geneva Switzerland.

7 Disclaimer

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8 Appendices

Appendix A – Test specifications
Appendix B – Test matrix
Appendix C – Result summary tables
Appendix D – Instrument response data
Appendix E – Test specimen details
Appendix F – Test photographs
Appendix G – Instrument details

Appendix A
Test Specifications

Appendix Prepared by: Drew Sherry

Appendix Checked by: Ross Dal Nevo

1. Quad bike steady state circular driving behaviour – test specification

ATV DYNAMIC HANDLING ASSESSMENT PROCEDURES

QUAD BIKE - STEADY STATE CIRCULAR DRIVING BEHAVIOUR TEST METHOD

Introduction

The purpose of this procedure is to provide a methodology by which the steady state circular driving behaviour (understeer gradient) of a quad bike can be measured. This procedure is modelled on ISO 4138:2012; Passenger Cars - Steady State Circular Driving behaviour - Open-loop test methods[i] which has been modified to suit the physical and dynamic characteristics of quad bikes.

The dynamic handling characteristics of a vehicle form a very important part of vehicle active safety, especially so for a vehicle that offers little or no crash protection, making crash avoidance ever more important. Any individual vehicle, together with its rider and environment will form a unique closed loop system. It is impossible to measure the performance of every vehicle in every circumstance. By establishing a standardised test procedure, the results for different vehicles can be compared.

A quad bike travelling at a moderate rate of 25 km/hr will cover almost 7 metres of ground every second. For a rider engaged in agricultural, local government or other attention demanding work, steering response characteristics must be precise and predictable under all riding circumstances. A vehicle that is slow to respond or that responds differently in similar circumstances, or whose response will change over time with the driver doing nothing, is an unpredictable and difficult to control vehicle. A vehicle that has an oversteer characteristic will also have a Critical Speed, which is the speed at which the vehicle will become dynamically unstable. Critical Speed is a function of both the oversteer gradient and the wheelbase. Short wheel-based vehicles (such as a quad bike) can have a Critical Speed within speed ranges that average riders would consider to be safe travel speeds. Vehicles that have an understeer characteristic do not have a Critical Speed. A farmer or other worker should not need to focus the bulk of their attention on the control of an unnecessarily unwieldy vehicle. The results of the tests described by this procedure provide a measure of the predictability of the vehicle response to rider steering input and its safe handling.

It is important to note that there is insufficient data available on the links between dynamic steering response and crash/injury causation for this measure to used for regulatory purposes. The results of this test is intended to be used as a comparator between different vehicles for consumer purposes.

1

1. Scope

This test procedure specifies the open-loop test method for determining the steady state circular driving behaviour of quad bikes. It is applicable to both agricultural (work type) and recreational (sports type) quad bikes.

2. References

The primary reference for this test procedure is ISO 4138:2012, Passenger Cars - Steady State Circular Driving behaviour - Open-loop test methods, including where applicable, the normative references used by that standard, such as:

- ISO 8855:2011, Road Vehicles - vehicle dynamics and road holding ability - Vocabulary,
- ISO 15037-1:2006, Road Vehicles - Vehicle dynamics test methods - Part 1 General conditions for passenger cars, and
- Society of Automotive Engineers (SAE) J266 - Steady-State Directional Control Test Procedures For Passenger Cars and Light Trucks

The American National Standard for Recreational Off-Highway Vehicles, ANSI/ROHVA 1 - 2011[ii] has also been referenced to develop this procedure.

3. General

Note: The test speeds and steering inputs have been chosen to be representative of a worker (rider whose primary concentration is on something other than the riding task) operating at a moderate speed and requiring to undertake a steering manoeuvre to avoid a hazard. While a wide variety of test speeds and steering inputs are possible, this sample is representative of the circumstances for a significant proportion of fatal and serious injury quad bike crashes that have occurred in the workplace in Australia[iii]. The rider in the described circumstance is often not engaged in an active riding style, (which may alter the steady state response of the vehicle), hence a neutral rider (inactive) has been used for the test methodology.

The primary aim of this test is to determine the quasi-steady state circular driving behaviour of a quad bike. The measured understeer or oversteer and where relevant, the point of transition between these characteristics, when combined with other handling characteristics, will provide an indication of an average rider's ability to control the vehicle during unexpected and unanticipated steering manoeuvres. The results can also be used to determine if the vehicle has a Critical Speed and if so, what it is.

4. Test Method

This test determines a measure of understeer or oversteer and where relevant, the point of transition between these characteristics. The information is determined by driving on a constant radius circle and varying the vehicle speed, either in set increments or by constant acceleration, then measuring the steering (handlebar) angle required to maintain a constant radius turn. Other test methods are available and are explained in full in Reference i, ISO 4138:2012, Passenger Cars - Steady State Circular Driving behaviour - Open-loop test methods

5. Reference System

The reference system specified in ISO 15037-1 applies as closely as practicable (given ISO 15037 is for passenger cars and includes references to driver and passenger etc).

The location of the origin of the vehicle axis system (X,Y,Z) is the reference point and therefore should be independent of the loading condition. It is fixed in the longitudinal plane of symmetry at half the wheelbase and at the height above the ground of the centre of gravity (CG) of the vehicle when loaded at rider only test mass (see 8.1).

6. Measuring Variables

The following variables shall be determined during the test:

- handlebar angle
- Steered wheel angle
- lateral acceleration
- yaw velocity
- longitudinal velocity

The following variables may be recorded if the situation or resources permit:

- roll angle
- sideslip angle
- lateral velocity
- handlebar torque
- longitudinal acceleration

7. Data Measuring Equipment

Data recording must be capable of a rate of at least 100 Hz or more. Minimum sampling rates and accuracy of the various parameters are shown in Table 1 below:

Parameter	Sensor Range	Resolution	Accuracy
Longitudinal Velocity	0 - 40 km/hr	0.2 km/hr	± 0.25% of full range
Lateral Acceleration	± 2g	≦ 0.01g	≦ 1% of full range
Yaw Velocity	± 200 deg/sec	≦ 1 deg/sec	≦ 5% of full range
Handlebar or Wheel angle	± 80 deg or ± 25 deg	≦ 0.25 deg	± 0.25 deg
Roll Angle *	± 45 deg	≦ 0.01 deg	± 2 deg

* If measured

Table 1: Parameter sampling rate, range and accuracy

8. Vehicle Test Conditions

8.1 Vehicle Loading.

The vehicle shall be in standard configuration without any accessories fitted. Tests shall be carried out at the 'rider only' configuration. Rider only test mass is the unloaded tare mass of the vehicle with all fluids at recommended level and the fuel tank filled to its rated capacity, plus 103 kgs, consisting of:

- rider and his/her safety clothing and equipment;
- outrigger system;
- sensor and data acquisition system,

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- plus any ballast required to achieve 103 kg total mass. (ballast is to be added in a saddle bag type device that applies the mass as closely as possible to the point of connection between the rider and the saddle when in a nominal upright seating position)
- If the vehicle needs to be trimmed in mass, fuel may be removed from the fuel tank, or underbody protection plates can be removed, to achieve the rider only test mass. Care should be taken to manage the vehicle mass distribution to preserve the CG location as closely as is practicable.

8.2 Cargo Loading

Additional tests may be performed with quad bike cargo racks loaded to manufacturers stated maximum load. Tests may be conducted with rider (103 kg as defined above) plus:

- front load only,
- front and rear combined load, and
- rear load only

Front and Rear combined sandbag loads sandwiched by plywood

Sandbags should be used to distribute the load evenly across the entire cargo rack surface area. Loads must be adequately secured to ensure no load shift during handling test manoeuvres.

Where the combined load mass plus rider exceed the manufacturers stated maximum load, cargo loads are to be distributed proportionally across the front and rear cargo racks. (e.g. if front maximum load of 40 kg + rear maximum load of 50 kg = 90 kg but when combined with 'rider load' of 103 kg exceeds the maximum vehicle load, the total allowable cargo load (maximum load - 103 kg rider mass = allowable load) is to be distributed proportionally front and rear. In this example, the allowable load is to be distributed 4/9th to front cargo rack and 5/9th to the rear cargo rack. Note: Load reduction does not necessarily apply to only the front or rear cargo loads when tested individually, which normally fall within the manufacturers allowable total load limit)

8.3 Tyres and Suspension

Tyres should be close to new condition. Tyres shall be inflated to manufacturers recommended pressures. Where more than one pressure is specified, the lowest value shall be used.

Adjustable suspension components shall be set to the values specified at the point of delivery by the dealer.

4

8.4 Warm Up

Vehicle must be warmed up adequately by driving, including circling in both left and right hand directions to warm up the tyres. Engine should be in the normal operating temperature range. No specific warm up procedure is required, however an experienced rider will be able to tell when their vehicle is suitably warmed up to ensure correct and consistent responses to throttle, steering and brake inputs are achieved.

8.5 Outriggers

Test vehicles shall be fitted with outriggers on both sides of the vehicle. These outriggers shall be designed to minimally influence dynamic test results and constructed so as to be strong enough to resist vehicle rollover during the prescribed testing.

8.6 Drive Train

The quad bike drive train should be set to its most open setting. For example, two wheel drive shall be used instead of four wheel drive and if a lockable differential is fitted, it shall be in the unlocked, or "open" configuration.

9. Test Surface and Ambient Conditions

9.1 Test Surface

The test surface shall be constructed of concrete or asphalt having a friction coefficient of at least 0.75. The slope of the surface shall be less than 1 degree (1.7%).

The test surface shall be dry and kept free from debris and substances that may affect test results during vehicle testing.

9.2 Ambient Conditions

Testing should be conducted within an ambient temperature range of 10 degrees to 30 degrees Celsius, in order to ensure rider comfort and safety from either wind chill or heat related stress or injury.

Testing should not be conducted when wind speed (constant wind or gusts) exceed 15 km/hr (at this wind speed a flag will stir up to 45 degrees from a flagpole but will not fully extend)

10. Test Procedure

10.1 General

The vehicle is driven at several speeds over a circular path of radius 7.6 metres[1]. The vehicle should remain on the desired path centreline, ± 0.2 m.

The directional control characteristics are determined from data obtained while driving the vehicle at successively higher speeds on the constant radius path. This procedure can be conducted in a very small area.

[1] Circle radius of 7.6 metres is specified by ANSI ROHVA 1: 2011 for testing SSV and generates lateral acceleration at or close to rollover limit at 25 km/hr or less (depending on vehicle)

There are two variations of the constant radius test. In the first, the vehicle is driven on the circular path at discrete, constant speeds. Data are taken when steady state is attained and measured for at least 3 sec. In the second method, the vehicle remains on the circular path with a continuous, slow speed increase, during which data are continuously taken.

10.2 Procedure

The Ackerman Steering Angle for the desired turn radius can be determined from the formula:

Ackerman Angle = arc tan (wheelbase / turn radius)

Record the calculated Ackerman Steering Angle.

Drive the vehicle onto the desired circular path at the lowest possible speed. Record data with the steering and throttle positions fixed, then drive the vehicle at the next speed at which data are to be taken.

Increase the level of lateral acceleration by increasing speed until it is no longer possible to maintain steady state conditions. The test will end when the vehicle does one of:

- roll onto two wheels,
- spin the rear end out of the turn,
- plough the front end out of the turn, or
- vehicle cannot go any faster

10.2.1 With discrete test speeds

Drive the vehicle onto the circle at each test speed. After attaining steady-state, in which the desired circular path is maintained within ± 0.2 m, the steering and vehicle speed are to be held constant for at least 3 sec.

10.2.2 With continuous speed increase

Steadily increase the speed and record data continuously for as long as the vehicle remains on the desired circular path within ± 0.2 m. The maximum rate of increase of lateral acceleration should be 0.1m/sec²/sec. If longitudinal velocity is used to control vehicle lateral acceleration, the rate of increase should be 0.15 km/hr/sec or 0.045 m/sec/sec (approx 10 km/hr per minute)

Note: Lateral acceleration is a function of velocity squared, but over the range of speeds being tested (generally 0 - 25 kph) the above rate of longitudinal speed increase will provide meaningful results.

Regardless of the method chosen, tests must be conducted in both left and right hand circle directions and repeated at least 3 times in each direction.

10.3 Rider Instructions.

10.3.1 The rider must keep his/her bottom in a central position on the saddle throughout the tests and only lean their upper body into the turn to counter the lateral acceleration being generated. Head and neck should remain in general alignment with the upper body.

10.3.2 Seat Reference Point. A standardised rider position is to be established, termed the 'seat reference point'. This point is established when a 95th %ile ATD is fitted to the Quad with the hands fixed to the handgrips and elbows/wrists straight. The pelvis is then centred on the saddle and shifted forward or aft until the spine box is vertical (±0.5 deg). A mark is placed on the saddle directly below the vee formed in the skin of the pelvis, below the instrument cavity. This seat reference point allows test riders to quickly adopt a standardised seating position by sitting their own buttocks on the saddle, with their coccyx positioned at the seat reference point.

11. Data Analysis

11.1 Steady State Values.

The steady-state values can be established as the average values during any time interval of 1 to 3 sec during which steady state is maintained.

11.2 Lateral Acceleration

Theoretically, steady-state characteristics should be determined as functions of centripetal acceleration, which is measured perpendicular to the path. Traditionally, these characteristics have been expressed as functions of lateral acceleration, which is measured perpendicular to the vehicle's x-axis. At steady state, lateral acceleration and centripetal acceleration differ by the Cosine of the sideslip angle. In most cases, the vehicle side-slip angle will be small, so the difference between lateral acceleration and centripetal acceleration can be ignored. Where large side-slip angles are observed, centripetal acceleration may be corrected to obtain lateral acceleration using the formula specified in Reference i, ISO 4138:2012, Passenger Cars - Steady State Circular Driving behaviour - Open-loop test methods, Section 9.2. The data should also be corrected for roll angle. As roll increases, gravity contributes to the perceived lateral acceleration. Therefore roll angle must be recorded and then a correction applied to the measured lateral acceleration.

11.3 Data Presentation

Measured data shall be plotted directly against lateral acceleration in accordance with Figure A-2 (and A-3 if Roll rate measured) of Annex A.

A curve is to be fitted to the data set, using a mathematical routine. The method of curve fitting shall be described in the presentation of results. Since each resulting curve will be described by a mathematical expression, it can be differentiated mathematically to produce the gradient as a continuous function of lateral acceleration.

NOTE: It has been found that the characteristics of some vehicles have discontinuities in slope, which are not easily dealt with by standard curve fitting and differentiating techniques. The method by which this is managed should be described in the presentation of results

11.4 Evaluation of characteristic values

7

Derive the gradient of the curve fitted to the experimental points. The values of gradient obtained are then plotted against the independent variable (in this case, lateral acceleration) to give a response graph.

By this means, the derived gradients can be obtained and plotted as functions of lateral acceleration, The gradients are plotted against lateral acceleration using the conventions: lateral acceleration on the *x* axis, left turns positive, right turns negative, while the gradients on the *y* axis are plotted using the normal sign convention.

11.4.1 Steering (handlebar) angle gradient and Steering (handlebar) torque gradient

Both steering (handlebar) angle gradient and steering (handlebar) torque gradient can be derived using formula detailed in ISO 8855:2011, 12.3.2.

11.5 Normalisation of results — Comparison of results from different vehicles

The results obtained above are to be normalised, so that meaningful comparisons between vehicles can be made. Further information about normalisation is provided in Annex D.

11.5.1 Normalisation with respect to steering ratio

This technique is essential for comparing results from vehicles of similar wheelbase. The procedure for measuring the steering ratio is given in Annex B. This ensures the comparison is made between steered wheel angles and not handlebar angles.

a) Understeer gradient

This gradient is determined by dividing the handlebar angle gradient by the steering ratio:
$\partial\delta_H/\partial a_y$ * $1/i_s$

11.5. 2 Normalisation with respect to wheelbase — Stability factor

This technique yields response values that can be used to compare vehicles of widely different sizes. See ISO 8855.

The stability factor is determined by dividing the understeer gradient by the wheelbase.

8

Annex A

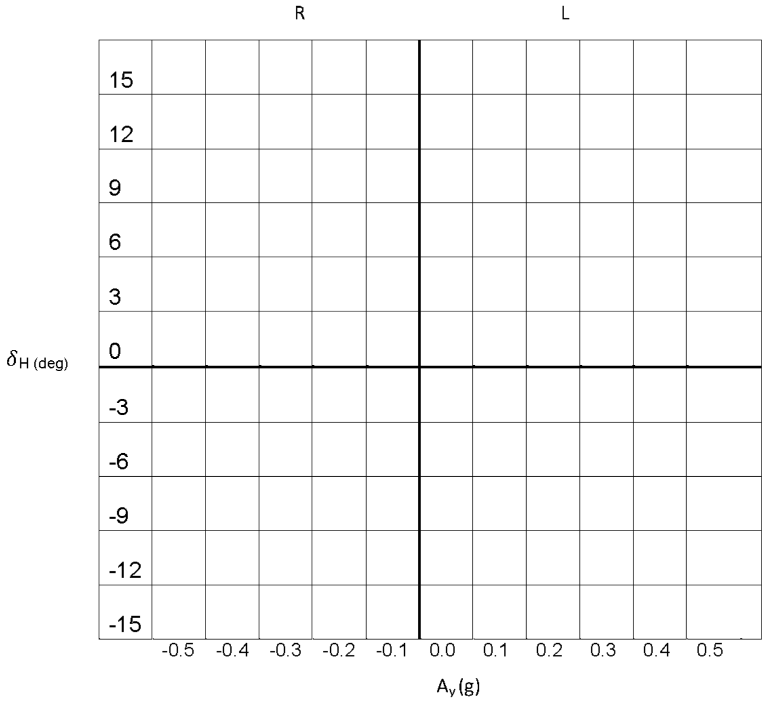
Test Report
General Data

Vehicle Identification:	**Make**	**Model**	**Year**	**Type**
	VIN or Manufacturer Serial Number			
	Steering Type			
	Suspension Type	**Front**	**Rear**	
	Engine Size			
	Tyres	**Make**	**Model**	**Size**
	Tyre Pressures	**Front kPa**	**Rear kPa**	
	Tyre Tread (depth / condition)			
	Rims	**Front**	**Rear**	
	Wheelbase			
	Track	**Front mm**	**Rear mm**	
	Steering Ratio			
	Other:			
Vehicle Loading	**Tare Mass**	**Left Front kgs**	**Right Front kgs**	**Sum kgs**
		Rear	**Rear**	**Sum**
	Rider Only Mass (103 kgs)	**Rider kgs**	**Test Eqpt kgs**	**Ballast kgs**
	Cargo Loading and location	**Front kgs**	**F+R kgs**	**Rear kgs**
Test Personnel	**Rider Name**			
	Observer			
Comments				

9

Annex A - 2

Presentation of Results



Vehicle: ....

Turning radius (constant). ....

A_y = Lateral Acceleration

δ_H = Handlebar angle (degrees)

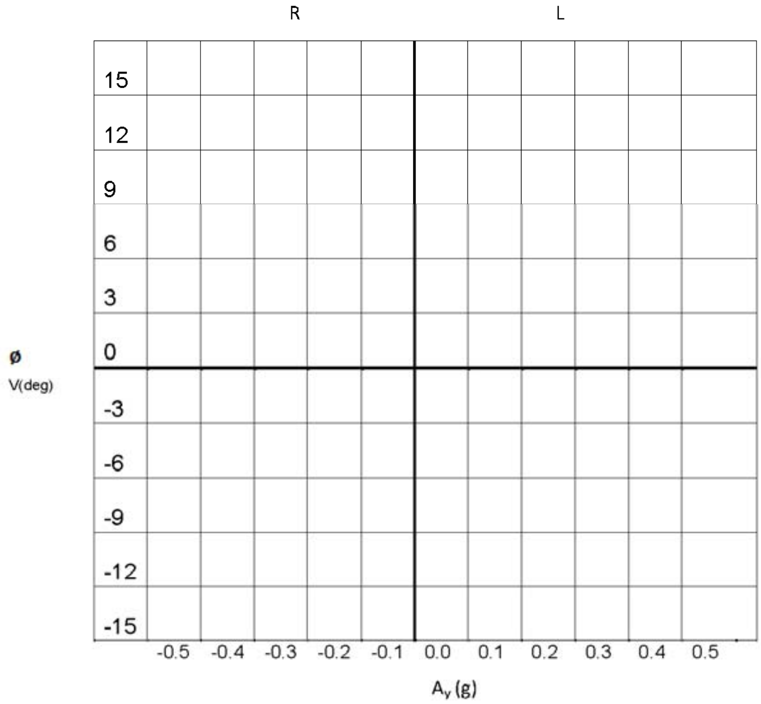
R = Right Turn

L = Left Turn

Handlebar Angle - Characteristic Values

Annex A - 3

Presentation of Results



Vehicle: ....

Turning radius (constant). ....

A_y = Lateral Acceleration

Ø_V = vehicle roll angle (degrees)

R = Right Turn

L = Left Turn

Vehicle Roll Angle - Characteristic Values

11

Annex B
(normative)

Determination of overall (static) steering ratio

B.1 Steering systems

Understeer gradients are stated in terms of the difference in cornering compliances between the front and rear road-wheel "axles". However, cornering compliances include deflections of the steering system due to elastic deformations. In order to include steering-system compliances, understeer is determined from measurements taken at the steering wheel. Steering-wheel angles are referred to the road wheels by the overall steering ratio.

Overall steering ratio (see ISO 8855) is a variable which describes the geometric relationship between steering- wheel angle and average road-wheel angle, measured under conditions of zero aligning moment and lateral force. If the steering system is significantly non-linear, each measured steering-wheel angle must be used together with a plot of average road-wheel angle versus steering-wheel angle to obtain the corresponding road-wheel steer angle. Steer angle gradients are obtained from a plot of road-wheel steer angle versus lateral acceleration.

B.2 Measurement

The overall steering ratio shall be determined for each vehicle test configuration over the range of steering wheel angles used during the test. The overall steering ratio will not, in general, represent the dynamic situation because of additional steering-system deflections caused by compliance and geometric effects. It is, however, suitable for removing the effect of different steering-system lever and gear ratios from comparisons of measurements from different vehicles. The compliance and geometric effects referred to above are then quite properly regarded as part of the vehicle handling characteristics.

B.3 Procedure

Using steering alignment radius plates and a handlebar angle sensor, test the range of steering inputs (handlebar angle) required to achieve the desired wheel steering angles (measured by radius plates). Record results on the table below for both left and right steering and determine the steering ratio.

Handlebar Angle versus Left and Right Wheel Angles (Averaged)

Handlebar Angle Degrees	Measured Steer Angle - Degrees		
	Left Wheel	Right Wheel	Average
0			
10			
20			
30			
40			
50			
-10			
-20			
-30			
-40			
-50			

Notes:

Ackerman steering requires increased steer to the inside wheel and reduced steer to the outside wheel on a turn. The average of the two represents the wheel angle required to follow the centreline of the test circle.

Steering Ratio = ratio handlebar turn (deg) : averaged wheel turn (deg)

Annex C

(informative)

General information — Theoretical basis for the test methods

The path curvature of a vehicle in steady-state turning at a given speed (i.e. in a given state of steady- state equilibrium) is determined by speed, steering-wheel angle, wheelbase and the elastic and kinematic characteristics of the front and rear steering systems, suspensions and tyres.

In the absence of kinematic and compliance steer effects — for example, at very low speeds — the low speed path radius is defined geometrically by wheelbase and by front- and rear-wheel steer angles. At increasing speed, steady-state turning results in centrifugal force, which produces kinematic and compliance steer and camber.

When expressed in degrees per metre per second squared (m/s^2) of lateral acceleration and lumped together, these *cornering compliances* produce steer angles and tyre slip angles in front and rear that modify the low-speed path radius. Cornering compliances subtract from the front and rear Ackermann steer angles.

Cornering compliances greater in front than rear increase path radius from the Ackermann condition and produce understeer, while those greater in the rear than in the front reduce path radius and cause oversteer. The difference between the total front and rear cornering compliance is called the *understeer gradient*, expressed in degrees per metre per second squared (or may be expressed in degrees per gravity (deg/g)). Similarly, the change in steering-wheel angle required to maintain a given radius with increasing lateral acceleration is called *steering-wheel angle gradient*, the change in roll angle with lateral acceleration is called *roll angle gradient*, etc.

The test procedures specified herein are designed to measure some of these various vehicle steady-state properties.

The sensitivities of the vehicle's responses to steering inputs are called yaw velocity gain (degrees per second per degree of steering-wheel movement), lateral acceleration gain (m/s^2 per degree of steering-wheel motion), sideslip gain, etc. These can be calculated from the vehicle speed, steering-wheel angle, steering ratio, wheelbase and understeer gradient, or they can be obtained directly from measured data.

Annex D

(informative)

Normalisation of Results

In any general case of a vehicle making a steady-state turn of given radius, the steer angle required will consist of two parts: that due to the Ackermann effect, which for a given radius is proportional to the wheelbase, and that due to the handling characteristics of the vehicle. In addition, the handle-bar angle corresponding to the required steer angle will depend on the overall steering ratio.

Thus, there are three quantities to be taken account of in the general case:

a) wheelbase, l;

b) overall steering ratio, i_s;

c) handle-bar angle gradient, $\partial\delta_{\mathrm{H}}/\partial a_{\mathrm{y}}$.

The units of the handle-bar angle gradient will be degrees per m/s^2 and, by convention, a vehicle with zero steering-wheel angle gradient — that is to say one which needs no movement of its steering wheel when changing speed on a curve of constant radius — is defined as a neutral-steer vehicle.

The handle-bar angle of a neutral-steer quad bike becomes a function only of turning radius, steering ratio and wheelbase.

The handle-bar angle gradient of any vehicle can be normalised by dividing the measured responses of the actual vehicle by the steering ratio.

The practical benefits of doing this are that the steering-wheel angle gradient of vehicles of similar sizes and different steering ratios can be compared analytically by comparing their normalized measured responses.

Comparison of measurements that have not been normalised will not clearly show differences in handle bar angle gradient because they also contain the effects of differences in steering ratio.

References:

[i] ISO 4138:2012, Passenger Cars - Steady State Circular Driving behaviour - Open-loop test methods

[ii] American National Standard Institute, American National Standard for Recreational Off-Highway Vehicles, (ANSI/ROHVA 1 - 2011), 11 July 2011

[iii] Lower T, Herde E, Fragar L. Quad bike deaths in Australia 2001 to 2010. *Journal of Health, Safety & Environment* 2012

2. Side-by-side vehicle steady state circular driving behaviour – test specification

ATV DYNAMIC HANDLING ASSESSMENT PROCEDURES

SIDE BY SIDE - STEADY STATE CIRCULAR DRIVING BEHAVIOUR TEST METHOD

Introduction

The purpose of this procedure is to provide a methodology by which the steady state circular driving behaviour (understeer gradient) of a quad bike can be measured. This procedure is modelled on ISO 4138:2012; Passenger Cars - Steady State Circular Driving behaviour - Open-loop test methods[i] which has been modified to suit the physical and dynamic characteristics of Side by Side vehicles.

The dynamic handling characteristics of a vehicle form a very important part of vehicle active safety, especially so for a vehicle that offers only limited crash protection, making crash avoidance ever more important. Any individual vehicle, together with its driver and environment will form a unique closed loop system. It is impossible to measure the performance of every vehicle in every circumstance. By establishing a standardised test procedure, the results for different vehicles can be compared.

A Side by Side vehicle, travelling at a moderate rate of 25 km/hr will cover almost 7 metres of ground every second. For a driver engaged in agricultural, local government or other attention demanding work, steering response characteristics must be precise and predictable under all riding circumstances. A vehicle that is slow to respond or that responds differently in similar circumstances, or whose response will change over time with the driver doing nothing, is an unpredictable and difficult to control vehicle. A vehicle that has an oversteer characteristic will also have a Critical Speed, which is the speed at which the vehicle will become dynamically unstable. Critical Speed is a function of both the oversteer gradient and the wheelbase. Short wheel-based vehicles (such as Side by Sides) can have a Critical Speed within speed ranges that average drivers would consider to be safe travel speeds. Vehicles that have an understeer characteristic do not have a Critical Speed. A farmer or other worker should not need to focus the bulk of their attention on the control of an unnecessarily unwieldy vehicle. The results of the tests described by this procedure provide a measure of the predictability of the vehicle response to driver steering input and hence its safe handling.

It is important to note that there is insufficient data available on the links between dynamic steering response and crash/injury causation for this measure to used for regulatory purposes. The results of this test is intended to be used as a comparator between different vehicles for consumer purposes.

1

1. Scope

This test procedure specifies the open-loop test method for determining the steady state circular driving behaviour of Side by Side vehicles. It is applicable to both agricultural (work type) and recreational (sports type) Side by Sides.

2. References

The primary reference for this test procedure is ISO 4138:2012, Passenger Cars - Steady State Circular Driving behaviour - Open-loop test methods, including where applicable, the normative references used by that standard, such as:

- ISO 8855:2011, Road Vehicles - vehicle dynamics and road holding ability - Vocabulary,
- ISO 15037-1:2006, Road Vehicles - Vehicle dynamics test methods - Part 1 General conditions for passenger cars, and
- Society of Automotive Engineers (SAE) J266 - Steady-State Directional Control Test Procedures For Passenger Cars and Light Trucks

The American National Standard for Recreational Off-Highway Vehicles, ANSI/ROHVA 1 - 2011[ii] has also been referenced to develop this procedure.

3. General

Note: The test speeds and steering inputs have been chosen to be representative of a worker operating the vehicle at a moderate speed and requiring to undertake a steering manoeuvre to avoid a hazard. While a wide variety of test speeds and steering inputs are possible, this sample is representative of foreseeable circumstances likely to be encountered in the workplace in Australia[iii].

The primary aim of this test is to determine the quasi-steady state circular driving behaviour of a Side by Side. The measured understeer or oversteer and where relevant, the point of transition between these characteristics, when combined with other handling characteristics, will provide an indication of an average driver's ability to control the vehicle during unexpected and unanticipated steering manoeuvres. The results can also be used to determine if the vehicle has a Critical Speed and if so, what it is.

4. Test Method

This test determines a measure of understeer or oversteer and where relevant, the point of transition between these characteristics. The information is determined by driving on a constant radius circle and varying the vehicle speed, either in set increments or by constant acceleration, then measuring the steering angle required to maintain a constant radius turn. Other test methods are available and are explained in full in Reference i, ISO 4138:2012, Passenger Cars - Steady State Circular Driving behaviour - Open-loop test methods

5. Reference System

The reference system specified in ISO 15037-1 applies as closely as practicable (given ISO 15037 is for passenger cars and includes references to driver and passenger etc).

The location of the origin of the vehicle axis system (X,Y,Z) is the reference point and therefore should be independent of the loading condition. It is fixed in the longitudinal plane of symmetry at half the wheelbase and at the height above the ground of the centre of gravity (CG) of the vehicle when loaded at driver only test mass (see 8.1).

6. Measuring Variables

The following variables shall be determined during the test:

- Steering wheel angle
- Steered wheel angle
- lateral acceleration
- yaw velocity
- longitudinal velocity

The following variables may be recorded if the situation or resources permit:

- roll angle
- sideslip angle
- lateral velocity
- handlebar torque
- longitudinal acceleration

7. Data Measuring Equipment

Data recording must be capable of a rate of at least 100 Hz or more. Minimum sampling rates and accuracy of the various parameters are shown in Table 1 below:

Parameter	Sensor Range	Resolution	Accuracy
Longitudinal Velocity	0 - 40 km/hr	0.2 km/hr	± 0.25% of full range
Lateral Acceleration	± 2g	≦ 0.01g	≦ 1% of full range
Yaw Velocity	± 200 deg/sec	≦ 1 deg/sec	≦ 5% of full range
Steering Wheel angle	± 80 deg or ± 25 deg	≦ 0.25 deg	± 0.25 deg
Roll Angle *	± 45 deg	≦ 0.01 deg	± 2 deg

* If measured

Table 1: Parameter sampling rate, range and accuracy

8. Vehicle Test Conditions

8.1 Vehicle Loading.

The vehicle shall be in standard configuration without any accessories fitted. Tests shall be carried out at the 'Driver only' loading condition. Driver only test mass is the unloaded tare mass of the vehicle with all fluids at recommended level and the fuel tank filled to its rated capacity, plus 103 kgs, consisting of:

- Driver and his/her safety clothing and equipment;
- outrigger system;
- sensor and data acquisition system,
- plus any ballast required to achieve 103 kg total mass. (ballast is to be added so that its mass acts as close as practicable to the driver's CG position)

3

8.2 Cargo Loading

Additional tests may be performed with Side by Side cargo tray loaded to manufacturers stated maximum load. Tests may be conducted with rider (103 kg as defined above) plus the rear load.

Sandbags should be used to distribute the load evenly across the entire cargo box area. Loads must be adequately secured to ensure no load shift occurs during handling test manoeuvres.

Side by Side cargo tray loaded with sandbags

8.3 Tyres and Suspension

Tyres should be close to new condition. Tyres shall be inflated to manufacturers recommended pressures. Where more than one pressure is specified, the lowest value shall be used.

Adjustable suspension components shall be set to the values specified at the point of delivery by the dealer.

8.4 Warm Up

Vehicle must be warmed up adequately by driving, including circling in both left and right hand directions to warm up the tyres. Engine should be in the normal operating temperature range. No specific warm up procedure is required, however an experienced rider will be able to tell when their vehicle is suitably warmed up to ensure correct and consistent responses to throttle, steering and brake inputs are achieved.

8.5 Outriggers

Test vehicles shall be fitted with outriggers on both sides of the vehicle. These outriggers shall be designed to minimally influence dynamic test results and constructed so as to be strong enough to resist vehicle rollover during the prescribed testing.

8.6 Drive Train

4

The vehicle's drive train should be set to its most open setting. For example, two wheel drive shall be used instead of four wheel drive and if a lockable differential is fitted, it shall be in the unlocked, or "open" configuration.

9. Test Surface and Ambient Conditions

9.1 Test Surface

The test surface shall be constructed of concrete or asphalt having a friction coefficient of at least 0.75. The slope of the surface shall be less than 1 degree (1.7%).

The test surface shall be dry and kept free from debris and substances that may affect test results during vehicle testing.

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Testing should be conducted within an ambient temperature range of 10 degrees to 30 degrees Celsius.

Testing should not be conducted when wind speed (constant wind or gusts) exceed 15 km/hr (at this wind speed a flag will stir up to 45 degrees from a flagpole but will not fully extend)

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There are two variations of the constant radius test. In the first, the vehicle is driven on the circular path at discrete, constant speeds. Data are taken when steady state is attained and measured for at least 3 sec. In the second method, the vehicle remains on the circular path with a continuous, slow speed increase, during which data are continuously taken.

10.2 Procedure

The Ackerman Steering Angle for the desired turn radius can be determined from the formula:

Ackerman Angle = arc tan (wheelbase / turn radius)

Record the calculated Ackerman Steering Angle.

Drive the vehicle onto the desired circular path at the lowest possible speed. Record data with the steering and throttle positions fixed, then drive the vehicle at the next speed at which data are to be taken.

[1] Circle radius of 7.6 metres is specified by ANSI ROHVA 1: 2011 for testing SSV and generates lateral acceleration approaching the rollover limit at around 25 km/hr (depending on vehicle)

Increase the level of lateral acceleration by increasing speed until it is no longer possible to maintain steady state conditions. The test will end when the vehicle does one of:

- roll onto two wheels,
- spin the rear end out of the turn,
- plough the front end out of the turn, or
- vehicle cannot go any faster

10.2.1 With discrete test speeds

Drive the vehicle onto the circle at each test speed. After attaining steady-state, in which the desired circular path is maintained within ± 0.2 m, the steering and vehicle speed are to be held constant for at least 3 sec.

10.2.2 With continuous speed increase

Steadily increase the speed and record data continuously for as long as the vehicle remains on the desired circular path within ± 0.2 m. The maximum rate of increase of lateral acceleration should be 0.1m/sec²/sec. If longitudinal velocity is used to control vehicle acceleration, the rate of increase should be 0.15 km/hr/sec or 0.045 m/sec/sec (approx 10 km/hr per minute)

Note: Lateral acceleration is a function of velocity squared, but over the range of speeds being tested (generally 0 - 25 kph) the above rate of longitudinal speed increase will provide meaningful results.

Regardless of the method chosen, tests must be conducted in both left and right hand circle directions and repeated at least 3 times in each direction.

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The steady-state values can be established as the average values during any time interval of 1 to 3 sec during which steady state is maintained.

11.2 Lateral Acceleration

Theoretically, steady-state characteristics should be determined as functions of centripetal acceleration, which is measured perpendicular to the path. Traditionally, these characteristics have been expressed as functions of lateral acceleration, which is measured perpendicular to the vehicle's x-axis. At steady state, lateral acceleration and centripetal acceleration differ by the Cosine of the sideslip angle. In most cases, the vehicle side-slip angle will be small, so the difference between lateral acceleration and centripetal acceleration can be ignored. Where large side-slip angles are observed, centripetal acceleration may be corrected to obtain lateral acceleration using the formula specified in Reference i, ISO 4138:2012, Passenger Cars - Steady State Circular Driving behaviour - Open-loop test methods, Section 9.2. The data should also be corrected for roll angle. As roll increases, gravity contributes to the perceived lateral acceleration. Therefore roll angle must be recorded and then a correction applied to the measured lateral acceleration.

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Derive the gradient of the curve fitted to the experimental points. The values of gradient obtained are then plotted against the independent variable (in this case, lateral acceleration) to give a response graph.

By this means, the derived gradients can be obtained and plotted as functions of lateral acceleration, The gradients are plotted against lateral acceleration using the conventions: lateral acceleration on the *x* axis, left turns positive, right turns negative, while the gradients on the *y* axis are plotted using the normal sign convention.

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Both steering angle gradient and steering torque gradient can be derived using formula detailed in ISO 8855:2011, 12.3.2.

11.5 Normalisation of results — Comparison of results from different vehicles

The results obtained above are to be normalised, so that meaningful comparisons between vehicles can be made. Further information about normalisation is provided in Annex D.

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This technique is essential for comparing results from vehicles of similar wheelbase. The procedure for measuring the steering ratio is given in Annex B. This ensures the comparison is made between steered wheel angles and not handlebar angles.

a) Understeer gradient

This gradient is determined by dividing the handlebar angle gradient by the steering ratio:
$\partial\delta_H/\partial a_y \ * \ 1/i_s$

11.5. 2 Normalisation with respect to wheelbase — Stability factor

This technique yields response values that can be used to compare vehicles of widely different sizes. See ISO 8855.

7

The stability factor is determined by dividing the understeer gradient by the wheelbase.

8

Annex A

Test Report
General Data

Vehicle Identification:	**Make**	**Model**	**Year**	**Type**
	VIN or Manufacturer Serial Number			
	Steering Type			
	Suspension Type	**Front**	**Rear**	
	Engine Size			
	Tyres	**Make**	**Model**	**Size**
	Tyre Pressures	**Front kPa**	**Rear kPa**	
	Tyre Tread (depth / condition)			
	Rims	**Front**	**Rear**	
	Wheelbase			
	Track	**Front mm**	**Rear mm**	
	Steering Ratio			
	Other:			
Vehicle Loading	**Tare Mass**	**Left Front kgs**	**Right Front kgs**	**Sum kgs**
		Rear	**Rear**	**Sum**
	Driver Only Mass (103 kgs)	**Driver kgs**	**Test Eqpt kgs**	**Ballast kgs**
	Cargo Loading			**Rear kgs**
Test Personnel	**Driver Name**			
	Observer			
Comments				

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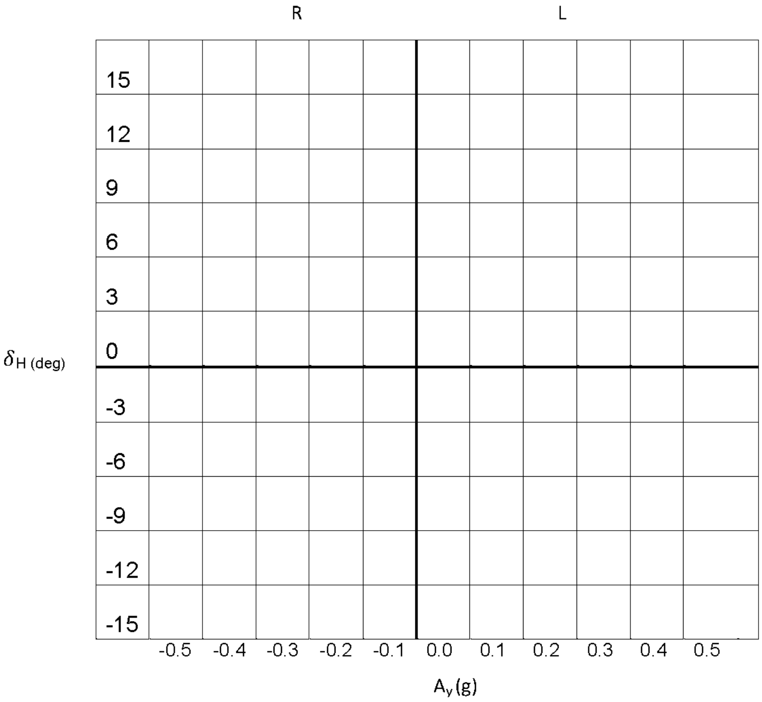
Annex A - 2

Presentation of Results



Vehicle: ....

Turning radius (constant). ....

A_y = Lateral Acceleration

δ_H = Steering wheel angle (degrees)

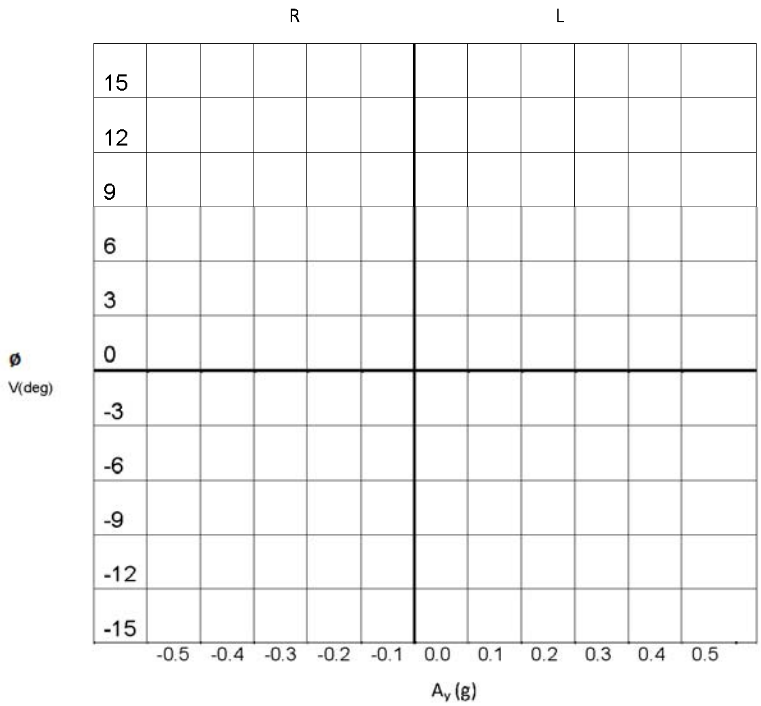
R = Right Turn

L = Left Turn

Steering Wheel Angle - Characteristic Values

Annex A - 3

Presentation of Results



Vehicle: ....

Turning radius (constant). ....

A_y = Lateral Acceleration

$ø_V$ = vehicle roll angle (degrees)

R = Right Turn

L = Left Turn

Vehicle Roll Angle - Characteristic Values

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Annex B
(normative)

Determination of overall (static) steering ratio

B.1 Steering systems

Understeer gradients are stated in terms of the difference in cornering compliances between the front and rear road-wheel "axles". However, cornering compliances include deflections of the steering system due to elastic deformations. In order to include steering-system compliances, understeer is determined from measurements taken at the steering wheel. Steering-wheel angles are referred to the road wheels by the overall steering ratio.

Overall steering ratio (see ISO 8855) is a variable which describes the geometric relationship between steering- wheel angle and average road-wheel angle, measured under conditions of zero aligning moment and lateral force. If the steering system is significantly non-linear, each measured steering-wheel angle must be used together with a plot of average road-wheel angle versus steering-wheel angle to obtain the corresponding road-wheel steer angle. Steer angle gradients are obtained from a plot of road-wheel steer angle versus lateral acceleration.

B.2 Measurement

The overall steering ratio shall be determined for each vehicle test configuration over the range of steering wheel angles used during the test. The overall steering ratio will not, in general, represent the dynamic situation because of additional steering-system deflections caused by compliance and geometric effects. It is, however, suitable for removing the effect of different steering-system lever and gear ratios from comparisons of measurements from different vehicles. The compliance and geometric effects referred to above are then quite properly regarded as part of the vehicle handling characteristics.

B.3 Procedure

Using steering alignment radius plates and a steering wheel angle sensor, test the range of steering inputs (steering wheel angle) required to achieve the desired wheel steering angles (measured by radius plates). Record results on the table below for both left and right steering and determine the steering ratio.

Steering Wheel Angle versus Left and Right Wheel Angles (Averaged)

Steering Wheel Angle Degrees	Measured Steer Angle - Degrees		
	Left Wheel	Right Wheel	Average
0			
10			
20			
30			
40			
50			
-10			
-20			
-30			
-40			
-50			

Notes:

Ackerman steering requires increased steer to the inside wheel and reduced steer to the outside wheel on a turn. The average of the two represents the wheel angle required to follow the centreline of the test circle.

Steering Ratio = ratio steering wheel turn (deg) : averaged wheel turn (deg)

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Annex C

(informative)

General information — Theoretical basis for the test methods

The path curvature of a vehicle in steady-state turning at a given speed (i.e. in a given state of steady- state equilibrium) is determined by speed, steering-wheel angle, wheelbase and the elastic and kinematic characteristics of the front and rear steering systems, suspensions and tyres.

In the absence of kinematic and compliance steer effects — for example, at very low speeds — the low, speed path radius is defined geometrically by wheelbase and by front- and rear-wheel steer angles. At increasing speed, steady-state turning results in centrifugal force, which produces kinematic and compliance steer and camber.

When expressed in degrees per metre per second squared (m/s^2) of lateral acceleration and lumped together, these *cornering compliances* produce steer angles and tyre slip angles in front and rear that modify the low-speed path radius. Cornering compliances subtract from the front and rear Ackermann steer angles.

Cornering compliances greater in front than rear increase path radius from the Ackermann condition and produce understeer, while those greater in the rear than in the front reduce path radius and cause oversteer. The difference between the total front and rear cornering compliance is called the *understeer gradient*, expressed in degrees per metre per second squared (or may be expressed in degrees per gravity (deg/g)). Similarly, the change in steering-wheel angle required to maintain a given radius with increasing lateral acceleration is called *steering-wheel angle gradient*, the change in roll angle with lateral acceleration is called *roll angle gradient*, etc.

The test procedures specified herein are designed to measure some of these various vehicle steady-state properties.

The sensitivities of the vehicle's responses to steering inputs are called yaw velocity gain (degrees per second per degree of steering-wheel movement), lateral acceleration gain (m/s^2 per degree of steering-wheel motion), sideslip gain, etc. These can be calculated from the vehicle speed, steering-wheel angle, steering ratio, wheelbase and understeer gradient, or they can be obtained directly from measured data.

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Annex D

(informative)

Normalisation of Results

In any general case of a vehicle making a steady-state turn of given radius, the steer angle required will consist of two parts: that due to the Ackermann effect, which for a given radius is proportional to the wheelbase, and that due to the handling characteristics of the vehicle. In addition, the handle-bar angle corresponding to the required steer angle will depend on the overall steering ratio.

Thus, there are three quantities to be taken account of in the general case:

a) wheelbase, l;

b) overall steering ratio, i_s;

c) steering wheel angle gradient, $\partial\delta_{\mathrm{H}}/\partial a_{\mathrm{y}}$.

The units of the steering wheel angle gradient will be degrees per m/s^2 and, by convention, a vehicle with zero steering-wheel angle gradient — that is to say one which needs no movement of its steering wheel when changing speed on a curve of constant radius — is defined as a neutral-steer vehicle.

The steering wheel angle of a neutral-steer side by side becomes a function only of turning radius, steering ratio and wheelbase.

The steering wheel angle gradient of any vehicle can be normalised by dividing the measured responses of the actual vehicle by the steering ratio.

The practical benefits of doing this are that the steering-wheel angle gradient of vehicles of similar sizes and different steering ratios can be compared analytically by comparing their normalized measured responses.

Comparison of measurements that have not been normalised will not clearly show differences in steering angle gradient because they also contain the effects of differences in steering ratio.

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References:

[i] ISO 4138:2012, Passenger Cars - Steady State Circular Driving behaviour - Open-loop test methods

[ii] American National Standard Institute, American National Standard for Recreational Off-Highway Vehicles, (ANSI/ROHVA 1 - 2011), 11 July 2011

[iii] Lower T, Herde E, Fragar L. Quad bike deaths in Australia 2001 to 2010. *Journal of Health, Safety & Environment* 2012

3. Procedure for application of trendline to steady state circular driving behaviour steering angle vs lateral acceleration graphs

Application of trendline to steady state circular driving behaviour Steering Angle vs. Lateral Acceleration scatter graphs

A trendline is to be superimposed over the existing steady state circular behaviour scatter graphs. This trendline shows whether the test vehicle exhibits understeer, neutral steer or oversteer characteristics and any transition point between characteristics during the steady state circular behaviour test.

Data from when the vehicle begins to maintain a steady steering angle to the time when the inside rear wheel no longer influences the vehicle's control should be used to plot the trendline. This data may include all or part of the data represented by the steady state circular behaviour scatter graphs.

Selecting the data for the Trendline

The following steps should be followed in order to select what data is to be used to plot the trendline.

1. Using the steering angle time domain trace, determine when a steady steering angle is maintained. Trim the data prior to this point (i.e. remove the data that represents when the vehicle is being driven onto the circle).

2. Using, but not limited to using, the steering angle and roll laser time domain traces as well as the test videos, determine when the inside rear wheel begins to no longer influence the vehicle's control. Trim the data beyond this point. Choosing when to trim the data will be performed differently depending on whether the vehicle has an open (unlocked) rear differential or not.

    a. For the vehicles without an open rear differential (most quad bikes), trim the data from when the inside rear (drive) wheel begins to lift off the test surface.

       For the Hisun in the locked rear differential case, the CF Moto and the Honda TRX700, where both the front and rear wheels lift at the same time, include all data up to this point.

    b. For the vehicles that contain an open rear differential (most SSVs), trim the data from when the inside rear (drive) wheel begins to lose traction and spin freely.

Presentation of the Trendline

Use a second order polynomial to develop the trendline. A second order polynomial generally provides a close relationship to the data trend. For all graphs, the trendline should only be displayed between 0.0 and 0.5g lateral acceleration. However, all the test scatter data is to be displayed in the plot.

Determining the Understeer Gradient

In the case where the understeer to oversteer transition point (or visa versa) occurs at a lateral acceleration of less than 0.1g or greater than 0.4g or no transition point is evident, the understeer gradient should be determined by a straight line relationship between the trendline values at 0.1g and 0.4g's. In the case where the trendline does not reach 0.4g, the gradient should be plotted between 0.1g and the maximum lateral acceleration achieved.

In the case where the understeer to oversteer transition point (or visa versa) occurs at a lateral acceleration between 0.1g and 0.4g, two understeer gradients should be determined by a straight line relationships between the trendline values at 0.1g and the transition point as well as between the transition point and 0.4g lateral acceleration. Where the trendline does not reach 0.4g, the gradient should be plotted between the transition point and the maximum lateral acceleration achieved.

4. Quad bike lateral transient response - test specification

ATV DYNAMIC HANDLING ASSESSMENT PROCEDURES
PART 1
QUAD BIKES

QUAD BIKE - LATERAL TRANSIENT RESPONSE TEST METHOD

Introduction

The purpose of this procedure is to provide a methodology by which the time it takes for a quad bike to respond to a standardised steering input can be measured. This procedure is modelled on ISO 7401:2011; Road Vehicles - Lateral transient response test methods - Open-loop test methods[i] and has been modified to suit the physical and dynamic characteristics of quad bikes.

The dynamic handling characteristics of a vehicle form a very important part of vehicle active safety, especially so for a vehicle that offers little or no crash protection, making crash avoidance ever more important. Any individual vehicle, together with its rider and environment will form a unique closed loop system. It is impossible to measure the performance of every vehicle in every circumstance. By establishing a standardised test procedure, the results for different vehicles can be compared.

A quad bike travelling at a moderate rate of 25 km/hr will cover almost 7 metres of ground every second. A hazard may appear unexpectedly in front of the rider, requiring a precise and rapid steering response in order to avoid it. The slower the steering response, the closer the rider will be carried to the hazard by the quad bike. Studies by McRuer and Klein[ii] showed that steering responses greater than 0.3 seconds are less suitable for average drivers to be able to control a vehicle during emergency response manoeuvres.

It is important to note that there is insufficient data available on the links between dynamic steering response and crash/injury causation for this measure to used for regulatory purposes. The results of this test is intended to be used as a comparator between different vehicles for consumer purposes.

1. Scope

This test procedure specifies the open-loop test method for determining the transient response behaviour of quad bikes. It is applicable to both agricultural (work type) and recreational (sports type) quad bikes.

2. References

The primary reference for this test procedure is ISO 7401, Road Vehicles - Lateral transient response test methods - Open-loop test methods, including where applicable, the normative references used by that standard, such as:

- ISO 8855, Road Vehicles - vehicle dynamics and road holding ability - Vocabulary, and
- ISO 1176, Road Vehicle s - Masses - Vocabulary and codes

3. General

Note: The test speeds and steering input have been chosen to be representative of a worker (rider whose primary concentration is on something other than the riding task) operating at a moderate speed and requiring to undertake an aggressive manoeuvre to avoid a hazard. While a wide variety of input speeds and steering inputs are possible, this sample is generally representative of the circumstances for a significant proportion of fatal and serious injury quad bike crashes that have occurred in the agricultural workplace in Australia[iii]. The rider in this type of circumstance is often not engaged in an active riding style, (which may improve the transient response of the vehicle), hence a neutral rider (inactive) has been used for the test methodology.

The primary aim of this test is to determine the transient response behaviour of a vehicle. Characteristic values relating to time will provide an indication how effectively a rider whose primary attention is focussed on something other than the riding task can undertake an emergency response manoeuvre with that vehicle.

Important characteristics in the time domain are:

a. time lag between handle bar angle, lateral acceleration and yaw velocity,
b. response time of lateral acceleration and yaw velocity,
c. lateral acceleration gain (lateral acceleration divided by handle bar angle),
d. yaw velocity gain (yaw velocity divided by handle bar angle); and
e. overshoot values (see 10.3)

In road vehicles, these characteristics show correlation with subjective evaluation during road driving and with steering response times identified by Wier et al[iv].

4. Test Method

This test determines a measure of lateral response time obtained from a step input.

5. Reference System

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The reference system specified in ISO 15037-1 applies as closely as practicable (given ISO 15037 is for passenger cars and includes references to driver and passenger etc).

The location of the origin of the vehicle axis system (X,Y,Z) is the reference point and therefore should be independent of the loading condition. It is fixed in the longitudinal plane of symmetry at half the wheelbase and at the height above the ground of the centre of gravity (CG) of the vehicle when loaded at rider only test mass (see 8.1).

6. Determining Variables

The following variables shall be determined during the test:

- handlebar angle
- lateral acceleration
- yaw velocity
- longitudinal velocity

The following variables may be recorded if resources permit:

- roll angle
- sideslip angle
- lateral velocity
- handlebar torque

7. Measuring Equipment

Data recording must be capable of a rate of at least 100 Hz and higher of possible. Minimum sampling rates and accuracy of the various parameters are shown in Table 1 below:

Parameter	Sensor Range	Resolution	Accuracy
Longitudinal Velocity	0 - 40 km/hr	0.2 km/hr	± 0.25% of full range
Lateral Acceleration	± 2g	≦ 0.01g	≦ 1% of full range
Yaw Velocity	± 200 deg/sec	≦ 1 deg/sec	≦ 5% of full range
Handlebar or Wheel angle	± 80 deg or ± 25 deg	≦ 0.25 deg	± 0.25 deg
Roll Angle *	± 45 deg	≦ 0.01 deg	± 2 deg

* If measured

Table 1: Parameter sampling rate, range and accuracy

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8. Vehicle and Test Conditions

8.1 Vehicle Loading.

The vehicle shall be in standard configuration without an accessories fitted. Tests shall be carried out at the 'rider only' configuration. Rider only test mass is the unloaded tare mass of the vehicle with all fluids at recommended level and the fuel tank filled to its rated capacity, plus 103 kgs, consisting of:

- rider and his/her safety clothing and equipment;
- outrigger system;
- sensor and data acquisition system,
- plus any ballast required to achieve 103 kg total mass. (ballast is to be added in a saddle bag type device that applies the mass as closely as possible to the point of connection between the rider and the saddle when in a nominal upright seating position)
- If the vehicle needs to be trimmed in mass, fuel may be removed from the fuel tank, or underbody protection plates can be removed, to achieve the rider only test mass. Care should be taken to manage the vehicle mass distribution to preserve the CG location as closely as is practicable.

8.2 Cargo Loading

Additional tests may be performed with quad bike cargo racks loaded to manufacturers stated maximum load. Tests may be conducted with rider (103 kg as defined above) plus:

- front load only,
- front and rear combined load, and
- rear load only

Sandbags should be used to distribute the load evenly across the entire cargo rack surface area. Loads must be adequately secured to ensure no load shift during handling test manoeuvres.

Front and Rear combined sandbag loads sandwiched by plywood

Where the combined load mass plus rider exceed the manufacturers stated maximum load, cargo loads are to be distributed proportionally across the front and rear cargo racks. (eg. if front maximum load of 40 kg + rear maximum load of 50 kg = 90 kg but when combined with 'rider load' of 103 kg exceeds the maximum vehicle load, the total allowable cargo load (maximum load - 103 kg rider mass = allowable load) is to be distributed proportionally front and rear. In this example, the allowable load is to be distributed 4/9th to front cargo rack and 5/9th to the rear cargo rack. Note: Load reduction does not necessarily apply to only the front or

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rear cargo loads when tested individually, which normally fall within the manufacturers allowable total load limit)

8.3 Tyres and Suspension

Tyres should be close to new condition. Tyres shall be inflated to manufacturers recommended pressures. Where more than one pressure is specified, the lowest value shall be used.

Adjustable suspension components shall be set to the values specified at the point of delivery by the dealer.

8.4 Warm Up

Vehicle must be warmed up adequately by driving, including circling in both left and right hand directions to warm up tyres. Engine should be in the normal operating temperature range. No specific warm up procedure is specified, however an experienced rider will be able to tell when their vehicle is suitably warmed up to ensure correct and consistent responses to throttle, steering and brake inputs are achieved.

8.5 Outriggers

Test vehicles shall be fitted with outriggers on both sides of the vehicle. These outriggers shall be designed to minimally influence dynamic test results and constructed so as to be strong enough to resist vehicle rollover during the prescribed testing.

8.6 Drive Train

The quad bike drive train should be set to its most open setting. For example, two wheel drive shall be used instead of four wheel drive and if a lockable differential is fitted, it shall be in the unlocked, or "open" configuration.

8.7. Test Surface and Ambient Conditions

8.7.1 Test Surface

The test surface shall be constructed of concrete or asphalt having a friction coefficient of at least 0.75. The slope of the surface shall be less than 1 degree (1.7%).

The test surface shall be dry and kept free from debris and substances that may affect test results during vehicle testing.

8.7.2 Ambient Conditions

Testing should be conducted within an ambient temperature range of 10 degrees to 30 degrees Celsius, in order to protect the test rider from either wind chill or heat related stress or injury. Testing should not be conducted when wind speed (constant wind or gusts) exceed 15 km/hr (at this wind speed a flag will stir up to 45 degrees from a flagpole but will not fully extend)

9. Test Procedure

9.1 The vehicle is driven in a straight line at a speed slightly above 20 km/hr and then a steering input introduced as rapidly as possible to a preselected value and maintained for several seconds after the vehicle motion variables have attained a steady state. The throttle position is to be maintained so as to hold the vehicle speed at 20 km/h during the turn. Throttle and steering stop devices may be used to aid the rider select and maintain the required throttle position and steering input. The time between 15% and 90% of the steering input shall not exceed 0.15 secs.

9.2 Lateral Acceleration to be demanded of the vehicle (in steady state turning) is 0.4g[1], at the test speed of 20 km/hr.

The steering input required to describe a circle to produce this value can be calculated using the Lateral Acceleration formula:

$$\mathbf{A_y = v^2 / 9.81 * r}$$

where:

A_y: Lateral Acceleration, in gravities
r: turn radius, in m
v: velocity, in m/sec

and the Ackerman Steering Angle for the desired lateral acceleration can be determined from the formula:

Ackerman Angle = arctan (wheelbase / turn radius)

Steering input can be pre-set using this equation, where the Ackerman Steering Angle is taken as the average of the steering angles of the left and right wheels. The procedure specified in American National Standard ANSI/ROHVA 1- 2011[v] Section 8.3.4 *Test Procedures*, (with minor modification) can be used to determine the wheel angles required.

Note: The vehicle may not describe a true Ackerman turn radius due to the plow effect caused by the fixed rear axle. Iterative testing at steady-state may be required to establish the corrected steer angle to achieve the required lateral acceleration.

Data shall be taken throughout the desired range of steering inputs and response variable outputs.

The test shall be repeated at least three times in each direction

9.4 Instructions to Riders. The rider must keep his/her bottom in a central position on the saddle throughout the tests and only lean their upper body into the turn, to counter the lateral acceleration being generated. Head and neck should remain in general alignment with the upper body. The rider should position his/herself so that their coccyx is immediately above the seat reference point.

[1] 0.4g is the lateral acceleration required by Reference i: ISO 7401:2011; Road Vehicles - Lateral transient response test methods - Open-loop test methods. If the quad cannot achieve a 0.4g lateral acceleration, the test should be conducted at 90% of the limit of lateral acceleration and the results annotated accordingly.

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9.5 Seat Reference Point. A standardised rider position is to be established, termed the 'seat reference point'. This point is established when a 95th %ile ATD is fitted to the Quad with the hands fixed to the handgrips and elbows/wrists straight. The pelvis is then centred on the saddle and shifted forward or aft until the spine box is vertical (±0.5 deg). A mark is placed on the saddle directly below the vee formed in the skin of the pelvis, below the instrument cavity. This seat reference point allows test riders to quickly adopt a standardised seating position by sitting their own buttocks on the saddle, with their coccyx positioned at the seat reference point.

10. Data Analysis

10.1 Response Time.

The transient response data reduction shall be carried out such that the origin for each response is the time at which the handlebar steering input is 50% complete This is the reference point from which all response times are measured. Response time is thus defined as the time, measured from this reference (T_0), for the vehicle transient response to first reach 90% of its new steady state value (see Figure 1 below)

10.2 Peak Response Time

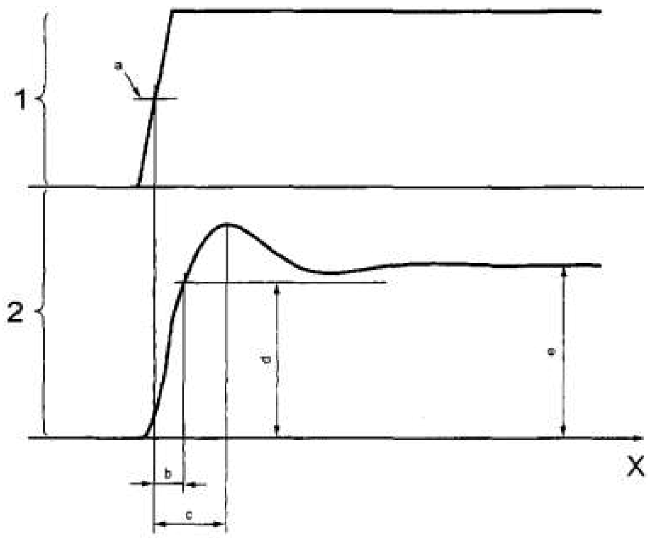
The peak response time is the time, measured from the reference point, for a vehicle's transient response to reach its peak value (see Figure 1 below)

10.3 Overshoot Values

Overshoot values are calculated as a ratio: the difference of peak value and steady-state value divided by the steady-state value.

10.4 Data Presentation

General data shall be presented in accordance with Annex A and Annex B. (A and B Annexes and Figure 1 below are copied from ISO 7401:2011)



Key

1	steering-wheel input	a	50 % level.	d	90 % steady state.
2	vehicle response time	b	Response time; T.	e	Steady state.
X	time	c	Peak response time; Tmax.		

Figure 1 — Response time and peak response time

10.3 Time Histories

Time histories of the variables used for data evaluation shall be plotted. If a curve is fitted to the data set, the method of curve fitting shall be described in the presentation of results in Annex B.

10.4 Time Response Data Summary

Record the appropriate values at Table B.1 (Annex B) for each combination of test speed and lateral acceleration used.

8

Annex A

Test Report
General Data

Vehicle Identification:	**Make**	**Model**		**Year**		**Type**
	VIN or Manufacturer Serial Number					
	Steering Type					
	Suspension Type	**Front**			**Rear**	
	Engine Size					
	Tyres	**Make**		**Model**		**Size**
	Tyre Pressures	**Front kPa**			**Rear kPa**	
	Tyre Tread (depth / condition)					
	Rims	**Front**			**Rear**	
	Wheelbase					
	Track	**Front mm**			**Rear mm**	
	Steering Ratio					
	Other:					
Vehicle Loading	**Tare Mass**	**Left Front kgs**		**Right Front kgs**		**Sum kgs**
		Rear		**Rear**		**Sum**
	Rider Only Mass (103 kgs)	**Rider kgs**		**Test Eqpt kgs**		**Ballast kgs**
	Cargo Loading and location	**Front kgs**		**F+R kgs**		**Rear kgs**
Test Personnel	**Rider Name**					
	Observer					
Comments						

9

Annex B
(normative)

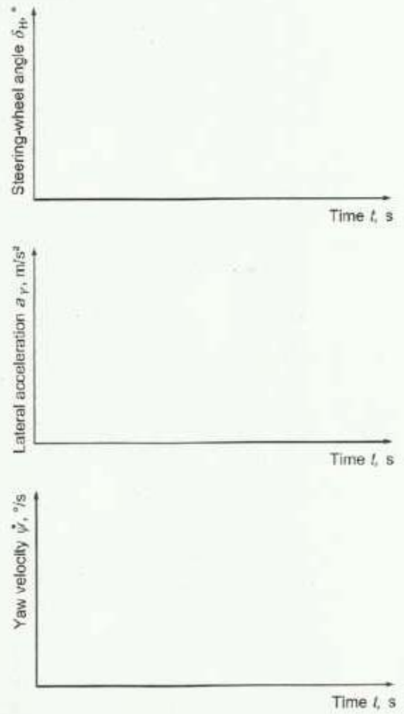
Test report — Presentation of results

B.1 Step input

Test number: ....

v_X = 20 km/hr .... km/h

a_Y = 0.4 m/sec² .... m/s²



$\delta_{H,SS}$ = ...
$50\ \%\ \delta_{H,SS}$ = ...
t_0 = ...

$a_{Y,SS}$ = ...
$90\ \%\ a_{Y,SS}$ = ...
$a_{Y,max}$ = ...
T_{aY} = ...
$T_{aY,max}$ = ...

$\dot{\psi}_{SS}$ = ...
$90\ \%\ \dot{\psi}_{ss}$ = ...
$\dot{\psi}_{max}$ = ...
$T_{\dot{\psi}}$ = ...
$T_{\dot{\psi},max}$ = ...

Figure B.1 — Step input — Time histories

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Table B.1 — Step input — Response data summary

Parameter	Symbol	Unit	Left turn	Right turn	Average
Steady-state yaw velocity response gain	$\left(\frac{\dot{\psi}}{\delta_H}\right)_{ss}$	s^{-1}			
Lateral acceleration response time	T_{aY}	s			
Yaw velocity response time	$T_{\dot{\psi}}$	s			
Lateral acceleration peak response time	$T_{aY,max}$	s			
Yaw velocity peak response time	$T_{\dot{\psi},max}$	s			
Overshoot value of lateral acceleration	U_{aY}	—			
Overshoot value of yaw velocity	$U_{\dot{\psi}}$	—			

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References:

[i] ISO 7401:2011[i]; Road Vehicles - Lateral transient response test methods - Open-loop test methods

[ii] McRuer and Klein, Automobile Controllability — Driver/Vehicle Response for Steering Control Volume I — Summary Report, Systems Technology Inc, February 1975

[iii] Lower T, Herde E, Fragar L. Quad bike deaths in Australia 2001 to 2010. *Journal of Health, Safety & Environment* 2012

[iv] Wier DH and Di Marco RJ, Correlation and Evaluation of Vehicle / Driver Directional Handling Data, 1978

[v] American National Standard for Recreational Off-Highway Vehicles ANSI.ROHVA 1 - 2011, American National Standard Institute, 11 July 2011

5. Side by side vehicle lateral transient response - test specification

ATV DYNAMIC HANDLING ASSESSMENT PROCEDURES
PART 2
SIDE BY SIDE VEHICLES

SIDE BY SIDE - LATERAL TRANSIENT RESPONSE TEST METHOD

Introduction

The purpose of this procedure is to provide a methodology by which the time it takes for a Side by Side vehicle to respond to a standardised steering input can be measured. This procedure is modelled on ISO 7401:2011; Road Vehicles - Lateral transient response test methods - Open-loop test methods[i] and has been modified to suit the physical and dynamic characteristics of Side by Side vehicles.

The dynamic handling characteristics of a vehicle form a very important part of vehicle active safety, especially so for a vehicle that offers little or no crash protection, making crash avoidance ever more important. Any individual vehicle, together with its rider and environment will form a unique closed loop system. It is impossible to measure the performance of every vehicle in every circumstance. By establishing a standardised test procedure, the results for different vehicles can be compared.

A Side by Side travelling at a moderate rate of 25 km/hr will cover almost 7 metres of ground every second. A hazard may appear unexpectedly in front of the rider, requiring a precise and rapid steering response in order to avoid it. The slower the steering response, the closer the rider will be carried to the hazard by the Side by Side. Studies by McRuer and Klein[ii] showed that steering responses greater than 0.3 seconds are less suitable for average drivers to be able to control a vehicle during emergency response manoeuvres.

It is important to note that there is insufficient data available on the links between dynamic steering response and crash/injury causation for this measure to used for regulatory purposes. The results of this test is intended to be used as a comparator between different vehicles for consumer purposes.

1

1. Scope

This test procedure specifies the open-loop test method for determining the transient response behaviour of Side by Side vehicles. It is applicable to both agricultural (work type) and recreational (sports type) Side by Sides.

2. References

The primary reference for this test procedure is ISO 7401, Road Vehicles - Lateral transient response test methods - Open-loop test methods, including where applicable, the normative references used by that standard, such as:

- ISO 8855, Road Vehicles - vehicle dynamics and road holding ability - Vocabulary, and
- ISO 1176, Road Vehicle s - Masses - Vocabulary and codes
- ANSI/ROHVA 1 - 2011 *Recreational Off-Highway Vehicles*

3. General

Note: The test speeds and steering input have been chosen to be representative of a worker operating at a moderate speed and requiring to undertake an aggressive manoeuvre to avoid a hazard. While a wide variety of input speeds and steering inputs are possible, this sample is generally representative of the circumstances in the agricultural workplace in Australia. .

The primary aim of this test is to determine the transient response behaviour of a vehicle. Characteristic values relating to time will provide an indication how effectively a driver can undertake an emergency response manoeuvre with that vehicle.

Important characteristics in the time domain are:

a. time lag between steering wheel angle, lateral acceleration and yaw velocity,
b. response time of lateral acceleration and yaw velocity,
c. lateral acceleration gain (lateral acceleration divided by steering wheel angle),
d. yaw velocity gain (yaw velocity divided by steering wheel angle); and
e. overshoot values (see 10.3)

In road vehicles, these characteristics show correlation with subjective evaluation during road driving and with steering response times identified by Wier et al[iii].

4. Test Method

This test determines a measure of lateral response time obtained from a step input.

5. Reference System

The reference system specified in ISO 15037-1 applies as closely as practicable (given ISO 15037 is for passenger cars and includes references to driver and passenger etc).

The location of the origin of the vehicle axis system (X,Y,Z) is the reference point and therefore should be independent of the loading condition. It is fixed in the longitudinal plane of symmetry at half the wheelbase and at the height above the ground of the centre of gravity (CG) of the vehicle when loaded at driver only test mass (see 8.1).

6. Determining Variables

The following variables shall be determined during the test:

- Steering wheel angle
- lateral acceleration
- yaw velocity
- longitudinal velocity

The following variables may be recorded if resources permit:

- roll angle
- sideslip angle
- lateral velocity
- Steering wheel torque

7. Measuring Equipment

Data recording must be capable of a rate of at least 100 Hz and higher of possible. Minimum sampling rates and accuracy of the various parameters are shown in Table 1 below:

Parameter	Sensor Range	Resolution	Accuracy
Longitudinal Velocity	0 - 40 km/hr	0.2 km/hr	± 0.25% of full range
Lateral Acceleration	± 2g	≦ 0.01g	≦ 1% of full range
Yaw Velocity	± 200 deg/sec	≦ 1 deg/sec	≦ 5% of full range
Steering Wheel angle	± 80 deg or ± 25 deg	≦ 0.25 deg	± 0.25 deg
Roll Angle *	± 45 deg	≦ 0.01 deg	± 2 deg

* If measured

Table 1: Parameter sampling rate, range and accuracy

8. Vehicle and Test Conditions

8.1 Vehicle Loading.

The vehicle shall be in standard configuration without an accessories fitted. Tests shall be carried out at the 'driver only' configuration. Driver only test mass is the unloaded tare mass of the vehicle with all fluids at recommended level and the fuel tank filled to its rated capacity, plus 103 kgs, consisting of:

- Test Driver and his/her safety clothing and equipment;
- outrigger system;
- sensor and data acquisition system,
- plus any ballast required to achieve 103 kg total mass. (ballast is to be added or removed so that its mass acts as close as practicable to the driver's CG position)

3

8.2 Cargo Loading

Additional tests may be performed with Side by Side cargo tray loaded up to manufacturers stated maximum load. Tests may be conducted with driver (103 kg as defined above) plus the rear load.

Sandbags should be used to distribute the load evenly across the entire cargo box surface area. Loads must be adequately secured to ensure no load shift during handling test manoeuvres.

Rear cargo tray loaded with sandbags

8.3 Tyres and Suspension

Tyres should be close to new condition. Tyres shall be inflated to manufacturers recommended pressures. Where more than one pressure is specified, the lowest value shall be used.

Adjustable suspension components shall be set to the values specified at the point of delivery by the dealer.

8.4 Warm Up

Vehicle must be warmed up adequately by driving, including circling in both left and right hand directions to warm up tyres. Engine should be in the normal operating temperature range. No specific warm up procedure is specified, however an experienced rider will be able to tell when their vehicle is suitably warmed up to ensure correct and consistent responses to throttle, steering and brake inputs are achieved.

8.5 Outriggers

Test vehicles shall be fitted with outriggers on both sides of the vehicle. These outriggers shall be designed to minimally influence dynamic test results and constructed so as to be strong enough to resist vehicle rollover during the prescribed testing.

8.6 Drive Train

The drive train should be set to its most open setting. For example, two wheel drive shall be used instead of four wheel drive and if a lockable differential is fitted, it shall be in the unlocked, or "open" configuration.

8.7. Test Surface and Ambient Conditions

8.7.1 Test Surface

The test surface shall be constructed of concrete or asphalt having a friction coefficient of at least 0.75. The slope of the surface shall be less than 1 degree (1.7%).

The test surface shall be dry and kept free from debris and substances that may affect test results during vehicle testing.

8.7.2 Ambient Conditions

Testing should be conducted within an ambient temperature range of 10 degrees to 30 degrees Celsius, in order to protect the test rider from either wind chill or heat related stress or injury. Testing should not be conducted when wind speed (constant wind or gusts) exceed 15 km/hr (at this wind speed a flag will stir up to 45 degrees from a flagpole but will not fully extend)

9. Test Procedure

9.1 Lateral Acceleration to be demanded of the vehicle (in steady state turning) is 0.4g[1], at the test speed of 20 km/hr.

9.2 The vehicle is driven in a straight line at slightly over 20 km/hr and then a steering input introduced as rapidly as possible to a preselected value and maintained for several seconds after the vehicle motion variables have attained a steady state. The throttle position is to be maintained so as to achieve a target 0.4g lateral acceleration at a velocity of 20 km/h. Throttle and steering stop devices may be used to aid the driver select and maintain the required throttle position and steering input. The time between 15% and 90% of the steering input shall not exceed 0.2 secs.

The steering input required to describe a circle to produce this value can be calculated using the Lateral Acceleration formula:

$$\mathbf{A_y = v^2 / 9.81 * r}$$

where:

A_y: Lateral Acceleration, in gravities
r: turn radius, in m
v: velocity, in m/sec

[1] 0.4g is the lateral acceleration required by Reference i: ISO 7401:2011; Road Vehicles - Lateral transient response test methods - Open-loop test methods. If the vehicle cannot achieve a 0.4g lateral acceleration, the test should be conducted at 90% of the limit of lateral acceleration and the results annotated accordingly.

and the Ackerman Steering Angle for the desired lateral acceleration can be determined from the formula:

Ackerman Angle = arctan (wheelbase / turn radius)

Steering input can be pre-set using this equation, where the Ackerman Steering Angle is taken as the average of the steering angles of the left and right wheels. The procedure specified in American National Standard ANSI/ROHVA 1- 2011[iv] Section 8.3.4 *Test Procedures*, (with minor modification) can be used to determine the wheel angles required. Note that vehicles with significant compliance in the steering system and tyres will not necessarily achieve the required lateral acceleration at steady state. Test measurement may be required.

Note: The vehicle may not describe a true Ackerman turn radius due to the plow effect caused by a fixed rear axle. Iterative testing at steady-state may be required to establish the corrected steer angle to achieve the required lateral acceleration.

Data shall be taken throughout the desired range of steering inputs and response variable outputs.

The test shall be repeated at least three times in each direction

10. Data Analysis

10.1 Response Time.

The transient response data reduction shall be carried out such that the origin for each response is the time at which the steering input is 50% complete This is the reference point from which all response times are measured. Response time is thus defined as the time, measured from this reference (T_0), for the vehicle transient response to first reach 90% of its new steady state value (see Figure 1 below)

10.2 Peak Response Time

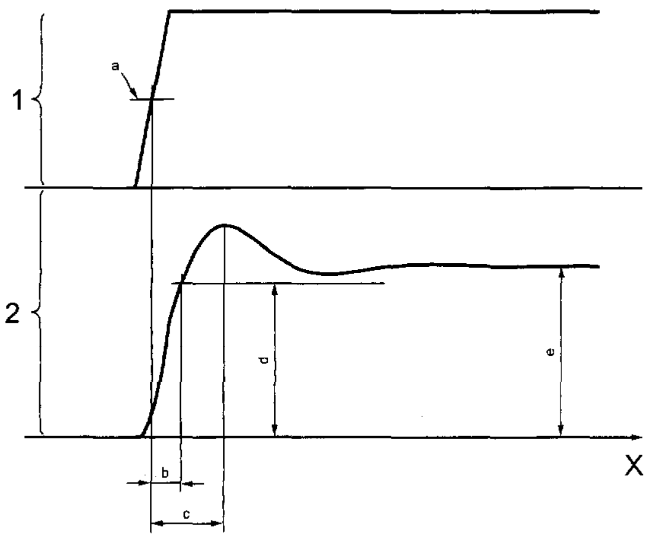
The peak response time is the time, measured from the reference point, for a vehicle's transient response to reach its peak value (see Figure 1 below)

10.3 Overshoot Values

Overshoot values are calculated as a ratio: the difference of peak value and steady-state value divided by the steady-state value.

10.4 Data Presentation

General data shall be presented in accordance with Annex A and Annex B. (Note: Annexe B and Figure 1 below are copied from ISO 7401:2011)



Key

1	steering-wheel input	a	50 % level.	d	90 % steady state.
2	vehicle response time	b	Response time; T.	e	Steady state.
X	time	c	Peak response time; Tmax.		

Figure 1 — Response time and peak response time

10.3 Time Histories

Time histories of the variables used for data evaluation shall be plotted. If a curve is fitted to the data set, the method of curve fitting shall be described in the presentation of results in Annex B.

10.4 Time Response Data Summary

Record the appropriate values at Table B.1 (Annex B) for each combination of test speed and lateral acceleration used.

7

Annex A

Test Report
General Data

Vehicle Identification:	Make	Model	Year	Type
	VIN or Manufacturer Serial Number			
	Steering Type			
	Suspension Type	Front	Rear	
	Engine Size			
	Tyres	Make	Model	Size
	Tyre Pressures	Front kPa	Rear kPa	
	Tyre Tread (depth / condition)			
	Rims	Front	Rear	
	Wheelbase			
	Track	Front mm	Rear mm	
	Steering Ratio			
	Other:			
Vehicle Loading	Tare Mass	Left Front kgs	Right Front kgs	Sum kgs
		Rear	Rear	Sum
	Driver Only Mass (103 kgs)	Driver kgs	Test Eqpt kgs	Ballast kgs
	Cargo Loading			Rear kgs
Test Personnel	Driver Name			
	Observer			
Comments				

Annex B
(normative)

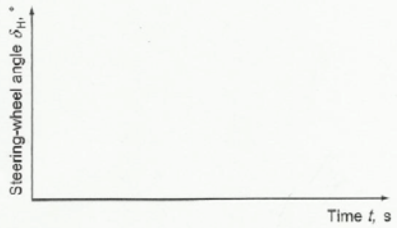
Test report — Presentation of results

B.1 Step input

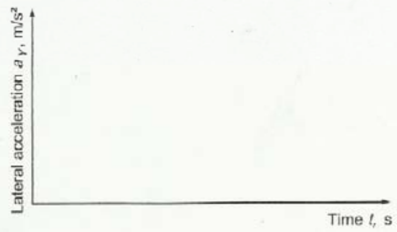
Test number: ....

v_X = 20 km/hr .... km/h

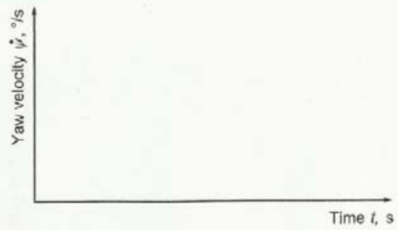
a_Y = 0.4 m/sec^2 .... m/s^2



$\delta_{H,SS}$ = ...
50 % $\delta_{H,SS}$ = ...
t_0 = ...



$a_{Y,SS}$ = ...
90 % $a_{Y,SS}$ = ...
$a_{Y,max}$ = ...
T_{aY} = ...
$T_{aY,max}$ = ...



$\dot{\psi}_{SS}$ = ...
90 % $\dot{\psi}_{ss}$ = ...
$\dot{\psi}_{max}$ = ...
$T_{\dot{\psi}}$ = ...
$T_{\dot{\psi},max}$ = ...

Figure B.1 — Step input — Time histories

9

Table B.1 — Step input — Response data summary

Parameter	Symbol	Unit	Left turn	Right turn	Average
Steady-state yaw velocity response gain	$\left(\frac{\dot{\psi}}{\delta_H}\right)_{ss}$	s^{-1}			
Lateral acceleration response time	T_{aY}	s			
Yaw velocity response time	$T_{\dot{\psi}}$	s			
Lateral acceleration peak response time	$T_{aY,max}$	s			
Yaw velocity peak response time	$T_{\dot{\psi},max}$	s			
Overshoot value of lateral acceleration	U_{aY}	—			
Overshoot value of yaw velocity	$U_{\dot{\psi}}$	—			

10

References:

i ISO 7401:2011[i]; Road Vehicles - Lateral transient response test methods - Open-loop test methods

ii McRuer and Klein, Automobile Controllability — Driver/Vehicle Response for Steering Control Volume I — Summary Report, Systems Technology Inc, February 1975

iii Wier DH and Di Marco RJ, Correlation and Evaluation of Vehicle / Driver Directional Handling Data, 1978

iv American National Standard for Recreational Off-Highway Vehicles ANSI.ROHVA 1 - 2011, American National Standard Institute, 11 July 2011

6. Bump obstacle perturbation - test specification

ATV DYNAMIC HANDLING ASSESSMENT PROCEDURES
PART 1
QUAD BIKES

QUAD BIKE - BUMP OBSTACLE TEST METHOD

Introduction

The purpose of this procedure is to provide a methodology by which the accelerations that will be imparted to the rider by a disturbance created by a bump obstacle input can be measured. Analysis of Australian fatal crash data involving quad bikes[1] indicates a significant proportion (over 19%) of fatal and serious injury crashes occur consequent to a rider striking a small bump type obstacle at low to moderate speeds. These impacts may result in the quad bike rolling onto the rider or the rider being otherwise thrown from the vehicle and striking another hazard.

The dynamic handling characteristics of a vehicle form a very important part of vehicle active safety, especially so for a vehicle that offers little or no crash protection, making crash avoidance ever more important. Any individual vehicle, together with its rider and environment will form a unique closed loop system. It is impossible to measure the performance of every vehicle and rider in every circumstance. By establishing a standardised test procedure, the characteristic results for different vehicles can be compared.

Bounce response to a bump is a function of the suspension geometry and spring and shock absorber design. In order to handle bumps well and minimise disturbance to the rider, the vehicle suspension must have adequate travel in both bump and rebound directions and also must provide appropriate ride stiffness and damping. Part of the ride stiffness includes the stiffness of the tyre. Due to the low pressure typically used in quad bikes, the tire is able to absorb small bumps simply through deformation with little disturbance to the vehicle and rider. Slightly larger bumps will involve both tyre and suspension reactions and will disturb the vehicle and its rider. The consequent vertical and lateral accelerations that are transferred to the rider by the perturbed quad bike are measured, to allow comparison of the vehicle's safe bump obstacle performance.

It is important to note that there is insufficient data available on the links between dynamic suspension response and crash/injury causation for this measure to used for regulatory purposes. The results of this test is intended to be used as a comparator between different vehicles for consumer information purposes.

[1] McIntosh A, and Patton, D; Quad Bike Fatalities in Australia: Examination of Crash Circumstances and Injury Patterns; Transport and Road Safety research, University of NSW. Draft report December 2013

1. Scope

This test procedure specifies the open-loop test method for determining the bump obstacle response behaviour of quad bikes. It is applicable to both agricultural (work type) and recreational (sports type) quad bikes.

2. References

This is a new test procedure designed in response to identified circumstances associated with fatal and serious injury crashes involving quad bikes. Recognised International Standards such as those listed below are used to describe the vehicle and general test arrangements:

- ISO 8855, Road Vehicles - vehicle dynamics and road holding ability - Vocabulary,
- ISO 1176, Road Vehicles - Masses - Vocabulary and codes
- SAE J963, SAE Recommended Practice: Anthropomorphic Test Device for Dynamic Testing, Society of Automotive Engineers, June 1968

3. General

The test speeds and bump obstacle height have been chosen to be representative of a worker (rider whose primary concentration is likely to be on something other than the riding task) operating at a moderate speed and impacting an unseen or unexpected bump obstacle hazard on one side of the vehicle only. While a wide variety of input speeds and obstacle configurations are possible, this sample is generally representative of the circumstances for at least a proportion of fatal and serious injury quad bike crashes that have occurred in the agricultural workplace in Australia[i]. The rider in this type of circumstance is often not engaged in an active riding style, (which would otherwise improve the outcome of the obstacle impact), hence a neutral rider (inactive) has been used for the test methodology.

The primary aim of this test is to determine the vertical and lateral accelerations that will be imparted to the rider by a vehicle that strikes a bump obstacle. Characteristic values will provide an indication of how significantly a rider, (who is not prepared for the bump and hence not riding so as to minimise the effect of the bump, ie. they are inert at the time of impact) will be disturbed by the bump obstacle impact.

4. Test Method

The obstacle is engaged by the ATV along each side of the vehicle separately. The approach/impact speed is set at 25km/hr and three passes are made on each side. The results of the three passes are analysed and the resultant lateral and vertical accelerations experienced at the ATD pelvis are then averaged arithmetically.

The test is repeated for the opposite side of the vehicle and the highest average response (left or right side) is reported as the Vehicle Bump Response. The Vehicle Bump Response provides an indication of how severely a rider sitting in a neutral riding position (non active riding) would be perturbed by the bump obstacle.

5. Reference System

The reference system specified in ISO 15037-1 applies as closely as practicable (given ISO 15037 is for passenger cars and includes references to driver and passenger etc).

The location of the origin of the vehicle axis system (X,Y,Z) is the reference point and therefore should be independent of the loading condition. It is fixed in the longitudinal plane of symmetry at half the wheelbase and at the height above the ground of the centre of gravity (CG) of the vehicle when loaded at rider only test mass (see 8.1).

6. Determining Variables

The following variables shall be determined during the test:

- Vertical and Lateral acceleration imparted to the test dummy when seated at the 'seat reference position' (see 8.2 below),
- Vehicle velocity, and
- Lateral displacement of the ATD from the centreline and Vehicle roll may be measured.

7. Measuring Equipment

Data recording must be capable of a rate of at least 100 Hz and higher of possible. Minimum sampling rates and accuracy of the various parameters are shown in Table 1 below:

Parameter	Sensor Range	Resolution	Accuracy
Longitudinal Velocity	0 - 40 km/hr	0.2 km/hr	± 0.25% of full range
Lateral Acceleration	± 5g	≦ 0.01g	≦ 1% of full range
Vertical Acceleration	± 5 g	≦ 0.01 g	≦ 1% of full range
ATD Lateral Displacement	± 0.2mm	≦ 0.05 mm	
Roll Angle *	± 45 deg	≦ 0.01 deg	± 2 deg

* If measured

Table 1: Parameter sampling rate, range and accuracy

8. Vehicle and Test Dummy Preparation and Conditions

8.1 Vehicle Loading.

The vehicle shall be in standard configuration without any accessories fitted. Tests shall be carried out at the 'rider only' configuration test mass. Rider only test mass is the unloaded tare mass of the vehicle with all fluids at recommended level and the fuel tank filled to its rated capacity, plus 103 kgs (± 0.5 kgs), consisting of a 95th percentile male Anthropomorphic Test Dummy (95%ile ATD) with attachment device / straps to hold the hands on the handlebar.

The mass of any installed sensor and data acquisition system is to be compensated for by removing the ATV battery and/or fuel from the fuel tank, until the rider only test mass is achieved. Care should be taken to minimise disturbance of the CG position of the system.

3

8.2 ATD Setup and Seat Reference Position.

The ATD is to be set up with vertical and lateral accelerometers installed in the instrument cavity of the pelvis. The test vehicle is parked on smooth flat ground. A 95%ile ATD 'rider' is positioned on the saddle, such that the hands fully grasp the handlebars with the web between the thumb and forefinger pushed against the inboard handgrip stops. The ATD hands are to be secured to the handgrips by way of tie-down strap or similar. The ATD shoes are adjusted into position so that the leading edge of the heel is positioned up against the rider foot peg rear edge. The shoes are not secured in this position for the bump obstacle test.

With the ADT elbows locked straight, the pelvis is positioned centrally on the saddle, then adjusted forward or aft until the upper torso spine box or rib attachment plate is vertical (± 0.5 °). A reference mark is placed on the saddle vertically below the 'vee' formed at the rear of the ATD pelvis flesh, directly below the instrument cavity. This mark is the seat reference position and identifies the position the ATD pelvis must be in prior to conduct of each test run. A measurement may be taken from the ATD to the quad bike frame for easy repositioning. ATD thighs and calves are to be pressed against the cowling. The ATD may have targets affixed to the rear of the pelvis to assist video analysis of the pelvis displacement.

The x and z positions of the Hip reference point (H Point) should be measured, relative to the rear edge of the foot peg.

The ATD head roll angle is positioned using the head gauge tool to be as close to horizontal as possible (0.0° ±0.5°).

ATD elbows are then to be splayed to 10 ° (set by using a marked Delrin bushing at the elbow joint).

A reference mark shall be placed centrally on the dashboard or instrument cluster and a measurement taken from the tip of the ATD nose to that reference mark. The set-up of the ATD for each test run should be within ±5mm of the original set-up measurement.

The ATD may be tethered at the pelvis so to allow free movement left and right to a maximum of 200mm travel, in order to minimise the risk of it falling off the quad bike during the test.

8.3 Instructions for vehicle set-up.

The quad bike is to be fitted with instrumentation to measure forward speed, vehicle roll angle and ATD displacement. Instrumentation and ballasting (addition or removal) should be distributed so as to minimise the effect on overall vehicle CoG.

Tow vehicle / cable and guide cable (if used) arrangements can be varied to suit available test location.

8.4 Tyres and Suspension

Tyres should be close to new condition. Tyres shall be inflated to manufacturers recommended pressures. Where more than one pressure is specified, the lowest value shall be used.

Adjustable suspension components shall be set to the values specified at the point of delivery by the dealer.

8.5 Vehicle Conditioning

The quad bike is towed through the bump obstacle test, hence no vehicle warm up is required. The vehicle should be conditioned in ambient temperatures between 10 and 30 degrees C for at least 2 hours prior to the test.

8.6 Drive Train

The quad bike drive train should be set to its most open setting. For example, two wheel drive shall be used instead of four wheel drive and if a lockable differential is fitted, it shall be in the unlocked, or "open" configuration. The quad bike transmission is to be in neutral.

8.7 Test Surface and Ambient Conditions

8.7.1 Test Surface

The test surface shall be constructed of concrete or asphalt having a friction coefficient of at least 0.75. The slope of the surface shall be less than 1 degree (1.7%).

The test surface shall be dry and kept free from debris and substances that may affect test results during vehicle testing.

A semi-circular (half pipe), smooth surfaced rigid step obstacle at least 400 mm long, with a maximum height above the test surface of 150mm (±5mm) is to be used for the bump obstacle test. The obstacle is to be secured to the test surface so as to ensure there is no significant movement when impacted.

8.7.2 Ambient Conditions

Testing should be conducted within an ambient temperature range of 10 degrees to 30 degrees Celsius.

Testing should not be conducted when wind speed (constant wind or gusts) exceed 15 km/hr (at this wind speed a flag will stir up to 45 degrees from a flagpole but will not fully extend)

9. Test Procedure

The vehicle is towed in a straight line at a test speed of 25 km/hr ±1 km/hr and the obstacle engaged at 90 degrees, with the tires of the vehicle striking approximately mid-point of the step obstacle. Tow vehicle is to reduce power/brake immediately prior to front wheel impact and the quad bike is to pass over the obstacle purely due to its own momentum. As a minimum, data is to be acquired from a point immediately prior to the front wheel impact, until 5 seconds after the rear wheel bump obstacle impact.

10. Data Analysis

10.1 Data Smoothing

Data obtained may be smoothed by use of a 10 step moving average filter process, to remove some of the inherent noise. (the knobbly type high mobility tires and imperfect ground surface, among other sources, can all contribute minor accelerations to the system which need to be smoothed by filtering).

10.2 Vertical and Lateral Acceleration.

The peak resultant vertical and lateral accelerations are measured at the ATD pelvis. Three successful test runs are to be arithmetically averaged and each of the three test results should lie within ± 10% of the average resultant acceleration. The larger of the two average resultants produced from the left and right side test runs becomes the vehicle bump obstacle response.

Annex:

A. Vehicle Test Report - General Data

Annex A

Test Report
General Data

Vehicle Identification:	**Make**	**Model**	**Year**		**Type**
	VIN or Manufacturer Serial Number				
	Steering Type				
	Suspension Type	**Front**		**Rear**	
	Engine Size				
	Tyres	**Make**	**Model**		**Size**
	Tyre Pressures	**Front** **kPa**		**Rear** **kPa**	
	Wheelbase				
	Track	**Front** **mm**		**Rear** **mm**	
	Other:				
Vehicle Loading	**Tare Mass**	**Left Front kgs**	**Right Front kgs**		**Sum kgs**
		Rear kgs	**Rear kgs**		**Sum kgs**
		Sum kgs	**Sum kgs**		**Total kgs**
	Rider Only Test Mass (Tare + 103 kgs)	**ATD and Test Eqpt** **kgs**	**Fuel Removed (less) kgs**		**Test Mass kgs**
Test Personnel	**Testing Officer**				
	Observer				
Comments					

7

Quad Bike Step Obstacle

Test Results Sheet

Test Speed	Peak Vertical and Lateral Resultant Acceleration at 25 kph	Comments
Left Side First Pass		
Left Side 2		
Left Side 3		
Left Side Bump Response	**Average Resultant**	
Right Side First Pass		
Right Side 2		
Right Side 3		
Right Side Bump Response	**Average Resultant**	

References:

[i] Lower T, Herde E, Fragar L. Quad bike deaths in Australia 2001 to 2010. *Journal of Health, Safety & Environment* 2012

8

Appendix B
Test matrix

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

1. Test number matrix

				Steady-state circular driving behaviour						Lateral transient response						Bump obstacle perturbation					
				Left			Right			Left			Right			Left			Right		
Vehicle make	Vehicle model	Surface	Additional Conditions	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Honda	TRX250	Asphalt	-	G130449	G130450	G130451	G130452	G130453	G130454	G130455	G130456	G130457	G130467	G130468	G130470	G130917	G130919	G130920	G130913	G130915	G130916
Honda	TRX500FM	Asphalt	-	G130395	G130396	G130397	G130398	G130399	G130400	G130401	G130402	G130403	G130404	G130405	G130406	G130951	G130952	G130954	G130948	G130949	G130950
Yamaha	YFM450FAP Grizzly	Asphalt	-	G130425	G130426	G130427	G130428	G130429	G130430	G130431	G130432	G130433	G130434	G130435	G130436	G130921	G130923	G130924	G130926	G130928	G130929
Polaris	Sportsman 450HO	Asphalt	-	G130681	G130682	G130683	G130684	G130685	G130686	G130997	G130998	G130999	G131000	G131001	G131002	G130955	G130956	G130957	G130959	G130960	G130961
Suzuki	Kingquad 400ASI	Asphalt	-	G130368	G130369	G130370	G130371	G130372	G130373	G130374	G130375	G130376	G130377	G130378	G130379	G130935	G130936	G130937	G130931	G130932	G130933
Kawasaki	KVF300	Asphalt	-	G130642	G130643	G130644	G130645	G130646	G130647	G130648	G130649	G130650	G130651	G130652	G130653	G130966	G130967	G130968	G130963	G130964	G130965
Kymco	MXU300	Asphalt	-	G130380	G130381	G130382	G130386	G130387	G130388	G130389	G130390	G130391	G130392	G130393	G130394	G130938	G130939	G130942	G130943	G130944	G130946
CF Moto	CF500	Asphalt	-	G130666	G130667	G130668	G130669	G130670	G130671	G130672	G130673	G130674	G130675	G130676	G130677	G130906	G130908	G130909	G130910	G130911	G130912
Yamaha	Rhino 700	Asphalt	-	G130744	G130745	G130746	G130747	G130748	G130749	G130750	G130751	G130752	G130753	G130754	G130755	***	***	***	***	***	***
Kubota	RTV500	Asphalt	-	G130865	G130866	G130867	G130868	G130869	G130870	G130871	G130872	G130873	G130874	G130875	G130876	***	***	***	***	***	***
John Deere	Gator XUV825i	Asphalt	-	G130853	G130854	G130855	G130856	G130857	G130858	G130859	G130860	G130861	G130862	G130863	G130864	***	***	***	***	***	***
Honda	Big red MUV700	Asphalt	-	G130792	G130793	G130794	G130798	G130799	G130800	G130805	G130806	G130807	G130808	G130809	G130810	***	***	***	***	***	***
Tomcar	TM2	Asphalt	-	G130407	G130408	G130409	G130410	G130411	G130412	G130413	G130414	G130415	G130416	G130417	G130418	***	***	***	***	***	***
Can-am	DS90X	Asphalt	-	G130732	G130733	G130734	G130729	G130730	G130731	G130735	G130736	G130737	G130738	G130739	G130740	G130990	G130991	G130992	G130993	G130994	G130996
Honda	TRX700XX	Asphalt	-	G130693	G130694	G130695	G130696	G130697	G130698	G130699	G130700	G130701	G130702	G130703	G130704	G130973	G130974	G130975	G130978	G130979	G130981
Yamaha	YFM250R Raptor	Asphalt	-	G130705	G130706	G130707	G130708	G130709	G130710	G130723	G130724	G130725	G130726	G130727	G130728	G130986	G130988	G130989	G130983	G130984	G130985
Honda	TRX250	Asphalt	Front load	G130522	G130523	G130524	G130525	G130526	G130527	G130528	G130529	G130530	G130531	G130532	G130533	***	***	***	***	***	***
Honda	TRX250	Asphalt	Rear load	G130498	G130499	G130500	G130501	G130502	G130503	G130504	G130505	G130506	G130507	G130508	G130509	***	***	***	***	***	***
Honda	TRX250	Asphalt	Front & rear load	G130510	G130511	G130512	G130513	G130514	G130515	G130516	G130517	G130518	G130519	G130520	G130521	***	***	***	***	***	***
Honda	TRX250	Grass	-	G130570	G130571	G130572	G130573	G130574	G130575	G130627	G130628	G130629	G130624	G130625	G130626	***	***	***	***	***	***
Honda	TRX250	Grass	Front load	G130612	G130613	G130614	G130615	G130616	G130617	G130618	G130619	G130620	G130621	G130622	G130623	***	***	***	***	***	***
Honda	TRX250	Grass	Rear load	G130582	G130583	G130584	G130585	G130586	G130587	G130609	G130610	G130611	G130606	G130607	G130608	***	***	***	***	***	***
Honda	TRX250	Grass	Front & rear load	G130594	G130595	G130596	G130597	G130598	G130599	G130600	G130601	G130602	G130603	G130604	G130605	***	***	***	***	***	***
Honda	TRX250	Asphalt	Quadbar CPD	G130546	G130547	G130548	G130549	G130550	G130551	G130552	G130553	G130554	G130555	G130556	G130557	***	***	***	***	***	***
Honda	TRX250	Asphalt	Lifeguard CPD	G130534	G130535	G130536	G130537	G130538	G130539	G130540	G130541	G130542	G130543	G130544	G130545	***	***	***	***	***	***
Honda	TRX250	Asphalt	Active riding, sideways	G130480	G130481	G130482	G130483	G130484	G130485	G130458	G130459	G130460	G130471	G130472	G130473	***	***	***	***	***	***
Honda	TRX250	Asphalt	Active riding, forwards	G130486	G130487	G130488	G130489	G130490	G130491	G130461	G130462	G130463	G130474	G130475	G130476	***	***	***	***	***	***
Honda	TRX250	Asphalt	Active riding, rearwards	G130492	G130493	G130494	G130495	G130496	G130497	G130464	G130465	G130466	G130477	G130478	G130479	***	***	***	***	***	***
Honda	TRX250	Asphalt	Higher tyre pressures	G130558	G130559	G130560	G130561	G130562	G130563	G130564	G130565	G130566	G130567	G130568	G130569	***	***	***	***	***	***
Honda	TRX250	Asphalt	Alternate rider	-	-	-	G130639	G130640	G130641	G130630	G130631	G130632	G130633	G130634	G130635	***	***	***	***	***	***
Yamaha	YFM450FAP Grizzly	Grass	-	G130443	G130444	G130445	G130446	G130447	G130448	G130440	G130441	G130442	G130437	G130438	G130439	***	***	***	***	***	***
Yamaha	YFM250R Raptor	Grass	-	G130717	G130718	G130719	G130720	G130721	G130722	G130711	G130712	G130713	G130714	G130715	G130716	***	***	***	***	***	***
Kawasaki	KVF300	Asphalt	Alternate rider	G130660	G130661	G130662	G130663	G130664	G130665	G130657	G130658	G130659	G130654	G130655	G130656	***	***	***	***	***	***
Honda	Big red MUV700	Asphalt	Rear differential locked	G130795	G130796	G130797	G130802	G130803	G130804	G130811	G130812	G130813	G130814	G130815	G130816	***	***	***	***	***	***
Honda	Big red MUV700	Asphalt	Rear load	G130817	G130818	G130819	G130820	G130821	G130822	G130823	G130824	G130825	G130826	G130827	G130828	***	***	***	***	***	***
Honda	Big red MUV700	Grass	-	G130847	G130848	G130849	G130850	G130851	G130852	G130841	G130842	G130843	G130844	G130845	G130846	***	***	***	***	***	***
Honda	Big red MUV700	Grass	Rear load	G130829	G130830	G130831	G130832	G130833	G130834	G130835	G130836	G130837	G130838	G130839	G130840	***	***	***	***	***	***
Yamaha	Rhino 700	Asphalt	Rear load	G130768	G130769	G130770	G130771	G130772	G130773	G130774	G130775	G130776	G130777	G130778	G130779	***	***	***	***	***	***
Yamaha	Rhino 700	Grass	-	G130756	G130757	G130758	G130759	G130760	G130761	G130762	G130763	G130764	G130765	G130766	G130767	***	***	***	***	***	***
Yamaha	Rhino 700	Grass	Rear load	G130786	G130787	G130788	G130789	G130790	G130791	G130780	G130781	G130782	G130783	G130784	G130785	***	***	***	***	***	***

*** Not tested in this configuration

Appendix C
Result summary tables

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

1. Steady state circular driving behaviour – result summary

					Steady-state circular driving behaviour values at limit of lateral acceleration - Circle direction Left					Steady-state circular driving behaviour values at limit of lateral acceleration - Circle direction Right				
Vehicle make	Vehicle model	Specimen number	Surface	Additional Conditions	Acceleration (g)	Average acceleration (g)	Velocity (km/h)	Average velocity (km/h)	Dynamic vehicle outcome	Acceleration (g)	Average acceleration (g)	Velocity (km/h)	Average velocity (km/h)	Dynamic vehicle outcome
Honda	TRX250	TS57199	Asphalt	-	0.48	0.46	21.5	21.8	Two wheel lift	0.46	0.46	21.1	21.4	Two wheel lift
					0.44		21.4		Two wheel lift	0.46		21.9		Two wheel lift
					0.46		22.4		Two wheel lift	0.45		21.1		Two wheel lift
Honda	TRX500FM	TS57200	Asphalt	-	0.53	0.52	20.9	21.5	Two wheel lift	0.52	0.52	23.4	23.6	Two wheel lift
					0.52		21.7		Two wheel lift	0.53		23.8		Two wheel lift
					0.52		21.9		Two wheel lift	0.50		23.5		Two wheel lift
Yamaha	YFM450FAP Grizzly	TS57201	Asphalt	-	0.47	0.46	21.3	21.0	Two wheel lift	0.43	0.41	21.4	21.3	Two wheel lift
					0.44		20.4		Two wheel lift	0.42		21.9		Two wheel lift
					0.47		21.3		Two wheel lift	0.38		20.6		Two wheel lift
Polaris	Sportsman 450HO	TS57202	Asphalt	-	0.60	0.61	24.1	24.0	Two wheel lift	0.56	0.55	24.5	24.2	Two wheel lift
					0.62		23.8		Two wheel lift	0.54		23.8		Two wheel lift
					0.61		24.2		Two wheel lift	0.54		24.2		Two wheel lift
Suzuki	Kingquad 400ASI	TS57203	Asphalt	-	0.50	0.51	22.1	22.2	Two wheel lift	0.43	0.45	21.2	22.3	Two wheel lift
					0.52		21.9		Two wheel lift	0.46		22.9		Two wheel lift
					0.50		22.7		Two wheel lift	0.46		22.9		Two wheel lift
Kawasaki	KVF300	TS57204	Asphalt	-	0.47	0.46	21.8	21.7	Two wheel lift	0.51	0.49	21.9	21.7	Two wheel lift
					0.46		21.4		Two wheel lift	0.49		21.8		Two wheel lift
					0.46		21.8		Two wheel lift	0.47		21.5		Two wheel lift
Kymco	MXU300	TS57205	Asphalt	-	0.41	0.39	21.0	20.8	Two wheel lift	0.33	0.36	18.3	19.9	Two wheel lift
					0.37		20.3		Two wheel lift	0.37		20.5		Two wheel lift
					0.40		21.1		Two wheel lift	0.38		20.9		Two wheel lift
CF Moto	CF500	TS57206	Asphalt	-	0.51	0.50	23.1	23.3	Two wheel lift	0.56	0.55	23.7	23.8	Two wheel lift
					0.48		23.4		Two wheel lift	0.56		23.9		Two wheel lift
					0.50		23.3		Two wheel lift	0.54		23.7		Two wheel lift
Yamaha	Rhino 700	TS57207	Asphalt	-	0.73	0.74	29.1	28.4	Two wheel lift	0.63	0.61	25.5	25.2	Two wheel lift
					0.76		28.1		Two wheel lift	0.60		26.0		Two wheel lift
					0.73		28.1		Two wheel lift	0.60		24.1		Two wheel lift
Kubota	RTV500	TS57208	Asphalt	-	0.62	0.62	24.6	24.6	Inside rear wheel broke traction (limiting speed)	0.54	0.54	22.7	22.7	Inside rear wheel broke traction (limiting speed)
					0.61		24.5		Inside rear wheel broke traction (limiting speed)	0.53		22.6		Inside rear wheel broke traction (limiting speed)
					0.63		24.7		Inside rear wheel broke traction (limiting speed)	0.54		22.8		Inside rear wheel broke traction (limiting speed)
John Deere	Gator XUV825i	TS57209	Asphalt	-	0.61	0.61	24.9	25.6	Inside rear wheel broke traction (limiting speed)	0.54	0.54	23.7	23.8	Inside rear wheel broke traction (limiting speed)
					0.60		24.7		Inside rear wheel broke traction (limiting speed)	0.55		23.4		Inside rear wheel broke traction (limiting speed)
					0.63		27.3		Inside rear wheel broke traction (limiting speed)	0.53		24.4		Inside rear wheel broke traction (limiting speed)
Honda	Big red MUV700	TS57210	Asphalt	-	0.64	0.66	25.8	25.5	Inside rear wheel broke traction (limiting speed)	0.55	0.56	23.6	23.8	Inside rear wheel broke traction (limiting speed)
					0.65		25.4		Inside rear wheel broke traction (limiting speed)	0.57		24.2		Inside rear wheel broke traction (limiting speed)
					0.69		25.4		Inside rear wheel broke traction (limiting speed)	0.57		23.7		Inside rear wheel broke traction (limiting speed)
Tomcar	TM2	TS58278	Asphalt	-	0.51	0.52	23.0	23.3	Drove out of circle (understeered out of circle)	0.49	0.49	24.9	24.0	Drove out of circle (understeered out of circle)
					0.52		22.9		Drove out of circle (understeered out of circle)	0.49		22.8		Drove out of circle (understeered out of circle)
					0.52		24.0		Drove out of circle (understeered out of circle)	0.50		24.2		Drove out of circle (understeered out of circle)
Can-am	DS90X	TS57211	Asphalt	-	0.67	0.68	23.9	24.4	Two wheel lift	0.53	0.54	24.3	24.2	Two wheel lift
					0.69		25.1		Two wheel lift	0.54		24.3		Two wheel lift
					0.69		24.3		Two wheel lift	0.54		23.9		Two wheel lift
Yamaha	YFM250R Raptor	TS57212	Asphalt	-	0.58	0.55	23.0	22.2	Two wheel lift	0.47	0.47	22.5	23.2	Two wheel lift
					0.54		22.2		Two wheel lift	0.48		23.4		Two wheel lift
					0.53		21.5		Two wheel lift	0.47		23.7		Two wheel lift
Honda	TRX700XX	TS57213	Asphalt	-	0.71	0.72	24.5	24.9	Two wheel lift	0.56	0.55	25.6	25.5	Two wheel lift
					0.72		25.0		Two wheel lift	0.54		26.0		Two wheel lift
					0.73		25.1		Two wheel lift	0.54		25.0		Two wheel lift

					Steady-state circular driving behaviour values at limit of lateral acceleration - Circle direction Left					Steady-state circular driving behaviour values at limit of lateral acceleration - Circle direction Right				
Vehicle make	Vehicle model	Specimen number	Surface	Additional Conditions	Acceleration (g)	Average acceleration (g)	Velocity (km/h)	Average velocity (km/h)	Dynamic vehicle outcome	Acceleration (g)	Average acceleration (g)	Velocity (km/h)	Average velocity (km/h)	Dynamic vehicle outcome
					0.42		21.0		Two wheel lift	0.45		21.5		Two wheel lift
Honda	TRX250	TS57199	Asphalt	Front load	0.42	0.43	21.7	21.4	Two wheel lift	0.46	0.45	21.2	21.3	Two wheel lift
					0.45		21.5		Two wheel lift	0.43		21.2		Two wheel lift
					0.46		21.3		Two wheel lift	0.46		21.4		Two wheel lift
Honda	TRX250	TS57199	Asphalt	Rear load	0.45	0.46	21.5	21.4	Two wheel lift	0.47	0.47	22.7	21.9	Two wheel lift
					0.47		21.4		Two wheel lift	0.47		21.6		Two wheel lift
					0.45		21.1		Two wheel lift	0.41		20.8		Two wheel lift
Honda	TRX250	TS57199	Asphalt	Front & rear load	0.45	0.45	21.2	21.3	Two wheel lift	0.42	0.43	21.0	20.9	Two wheel lift
					0.46		21.6		Two wheel lift	0.45		21.0		Two wheel lift
					0.48		21.5		Two wheel lift	0.41		21.0		Two wheel lift
Honda	TRX250	TS57199	Grass	-	0.45	0.47	22.0	21.7	Two wheel lift	0.41	0.41	21.5	21.2	Two wheel lift
					0.48		21.7		Two wheel lift	0.41		21.2		Two wheel lift
					0.45		21.2		Two wheel lift	0.38		20.6		Two wheel lift
Honda	TRX250	TS57199	Grass	Front load	0.45	0.45	19.5	20.2	Two wheel lift	0.39	0.38	21.1	20.7	Two wheel lift
					0.46		19.9		Two wheel lift	0.38		20.4		Two wheel lift
					0.46		21.1		Two wheel lift	0.41		20.8		Two wheel lift
Honda	TRX250	TS57199	Grass	Rear load	0.46	0.45	22.6	21.7	Two wheel lift	0.41	0.41	21.2	21.4	Two wheel lift
					0.44		21.3		Two wheel lift	0.42		22.1		Two wheel lift
					0.42		20.2		Two wheel lift	0.40		21.0		Two wheel lift
Honda	TRX250	TS57199	Grass	Front & rear load	0.43	0.43	20.9	20.9	Two wheel lift	0.40	0.40	20.5	20.7	Two wheel lift
					0.44		21.5		Two wheel lift	0.41		20.5		Two wheel lift
					0.44		22.4		Two wheel lift	0.46		21.7		Two wheel lift
Honda	TRX250	TS57199+CPD1	Asphalt	Quadbar CPD	0.47	0.45	22.3	22.0	Two wheel lift	0.44	0.47	21.5	21.9	Two wheel lift
					0.44		21.4		Two wheel lift	0.50		22.6		Two wheel lift
					0.45		21.4		Two wheel lift	0.43		21.4		Two wheel lift
Honda	TRX250	TS57199+CPD2	Asphalt	Lifeguard CPD	0.46	0.46	20.9	21.4	Two wheel lift	0.46	0.45	21.6	21.9	Two wheel lift
					0.46		21.9		Two wheel lift	0.46		22.6		Two wheel lift
					0.57		23.2		Two wheel lift	0.53		22.8		Two wheel lift
Honda	TRX250	TS57199	Asphalt	Active riding, sideways	0.57	0.57	22.9	22.9	Two wheel lift	0.52	0.52	23.0	23.1	Two wheel lift
					0.56		22.7		Two wheel lift	0.52		23.4		Two wheel lift
					0.47		21.7		Two wheel lift	0.44		21.5		Two wheel lift
Honda	TRX250	TS57199	Asphalt	Active riding, forwards	0.48	0.47	21.2	21.5	Two wheel lift	0.43	0.44	20.8	21.2	Two wheel lift
					0.45		21.6		Two wheel lift	0.46		21.2		Two wheel lift
					0.46		22.0		Two wheel lift	0.51		21.8		Two wheel lift
Honda	TRX250	TS57199	Asphalt	Active riding, rearwards	0.47	0.47	21.7	22.0	Two wheel lift	0.46	0.49	22.7	22.1	Two wheel lift
					0.47		22.3		Two wheel lift	0.50		21.8		Two wheel lift
					0.49		21.7		Two wheel lift	0.50		22.9		Two wheel lift
Honda	TRX250	TS57199	Asphalt	Higher tyre pressures	0.47	0.48	22.0	22.1	Two wheel lift	0.51	0.49	22.8	22.7	Two wheel lift
					0.48		22.5		Two wheel lift	0.47		22.4		Two wheel lift
					N/A		N/A		Two wheel lift	0.44		22.6		Two wheel lift
Honda	TRX250	TS57199	Asphalt	Alternative rider	N/A	N/A	N/A	N/A	Two wheel lift	0.44	0.44	22.6	22.4	Two wheel lift
					N/A		N/A		Two wheel lift	0.45		21.9		Two wheel lift
					0.41		20.1		Two wheel lift	0.43		21.9		Two wheel lift
Yamaha	YFM450FAP Grizzly	TS57201	Grass	-	0.50	0.46	23.4	22.1	Two wheel lift	0.43	0.43	22.5	22.0	Two wheel lift
					0.48		22.9		Two wheel lift	0.42		21.6		Two wheel lift
					0.58		22.0		Two wheel lift	0.43		21.3		Two wheel lift
Yamaha	YFM250R Raptor	TS57212	Grass	-	0.53	0.56	21.5	22.0	Two wheel lift	0.45	0.44	22.0	21.5	Two wheel lift
					0.56		22.4		Two wheel lift	0.44		21.2		Two wheel lift

					Steady-state circular driving behaviour values at limit of lateral acceleration - Circle direction Left					Steady-state circular driving behaviour values at limit of lateral acceleration - Circle direction Right				
Vehicle make	Vehicle model	Specimen number	Surface	Additional Conditions	Acceleration (g)	Average acceleration (g)	Velocity (km/h)	Average velocity (km/h)	Dynamic vehicle outcome	Acceleration (g)	Average acceleration (g)	Velocity (km/h)	Average velocity (km/h)	Dynamic vehicle outcome
					0.44		22.8		Two wheel lift	0.47		21.5		Two wheel lift
Kawasaki	KVF300	TS57204	Asphalt	Alternative rider	0.41	0.42	21.4	21.9	Two wheel lift	0.50	0.49	22.4	21.8	Two wheel lift
					0.42		21.6		Two wheel lift	0.50		21.5		Two wheel lift
					0.74		27.1		Spun out (oversteered into circle)	0.68		27.0		Spun out (oversteered into circle)
Honda	Big red MUV700	TS57210	Asphalt	Rear differential locked	0.75	0.75	27.6	27.0	Spun out (oversteered into circle)	0.66	0.67	26.7	26.9	Spun out (oversteered into circle)
					0.75		26.4		Spun out (oversteered into circle)	0.67		27.0		Spun out (oversteered into circle)
					0.63		25.8		Inside rear wheel broke traction (limiting speed)	0.55		24.5		Inside rear wheel broke traction (limiting speed)
Honda	Big red MUV700	TS57210	Asphalt	Rear load	0.62	0.62	24.3	25.2	Inside rear wheel broke traction (limiting speed)	0.56	0.55	24.5	24.7	Inside rear wheel broke traction (limiting speed)
					0.62		25.4		Inside rear wheel broke traction (limiting speed)	0.55		25.2		Inside rear wheel broke traction (limiting speed)
					0.55		22.4		Inside rear wheel broke traction (limiting speed)	0.56		22.7		Inside rear wheel broke traction (limiting speed)
Honda	Big red MUV700	TS57210	Grass	-	0.53	0.53	22.9	22.7	Inside rear wheel broke traction (limiting speed)	0.47	0.59	22.3	22.5	Inside rear wheel broke traction (limiting speed)
					0.52		22.7		Inside rear wheel broke traction (limiting speed)	0.74		22.6		Inside rear wheel broke traction (limiting speed)
					0.54		22.9		Drove out of circle (understeered out of circle)	0.44		23.1		Drove out of circle (understeered out of circle)
Honda	Big red MUV700	TS57210	Grass	Rear load	0.52	0.52	22.3	23.1	Drove out of circle (understeered out of circle)	0.44	0.43	24.3	23.0	Drove out of circle (understeered out of circle)
					0.51		24.2		Drove out of circle (understeered out of circle)	0.42		21.7		Drove out of circle (understeered out of circle)
					0.73		27.2		Two wheel lift	0.69		24.2		Two wheel lift
Yamaha	Rhino 700	TS57207	Asphalt	Rear load	0.73	0.74	24.0	25.9	Two wheel lift	0.73	0.68	25.8	25.2	Two wheel lift
					0.77		26.4		Two wheel lift	0.63		25.5		Two wheel lift
					0.65		24.3		Spun out (oversteered into circle)	0.52		22.4		Spun out (oversteered into circle)
Yamaha	Rhino 700	TS57207	Grass	-	0.69	0.66	25.3	24.8	Spun out (oversteered into circle)	0.59	0.56	23.4	23.4	Spun out (oversteered into circle)
					0.63		24.9		Spun out (oversteered into circle)	0.56		24.4		Spun out (oversteered into circle)
					0.66		26.7		Spun out (oversteered into circle)	0.57		23.9		Spun out (oversteered into circle)
Yamaha	Rhino 700	TS57207	Grass	Rear load	0.63	0.63	23.9	25.0	Spun out (oversteered into circle)	0.56	0.57	23.7	23.5	Spun out (oversteered into circle)
					0.60		24.4		Spun out (oversteered into circle)	0.57		22.9		Spun out (oversteered into circle)

2. Steady state circular driving behaviour – steering gradient summary

Vehicle make	Vehicle model	Specimen number	Surface	Additional Conditions	Steering gradient - circle direction Left							Steering gradient - circle direction Right						
					Steering gradient transition point (lateral acceleration g)	Steering gradient (°/g) between 0.1g & 0.4g lateral acceleration	Average steering gradient (°/g) between 0.1g & 0.4g lateral acceleration	Steering gradient (°/g) between 0.1g lateral acceleration & transition point	Average steering gradient (°/g) between 0.1g lateral acceleration & transition point	Steering gradient (°/g) between transition point & 0.4g lateral acceleration	Average steering gradient (°/g) between transition point & 0.4g lateral acceleration	Steering gradient transition point (lateral acceleration g)	Steering gradient (°/g) between 0.1g & 0.4g lateral acceleration	Average steering gradient (°/g) between 0.1g & 0.4g lateral acceleration	Steering gradient (°/g) between 0.1g lateral acceleration & transition point	Average steering gradient (°/g) between 0.1g lateral acceleration & transition point	Steering gradient (°/g) between transition point & 0.4g lateral acceleration	Average steering gradient (°/g) between transition point & 0.4g lateral acceleration
					0.02	-7.14		-		-		0.05	-9.04		-		-	
Honda	TRX250	TS57199	Asphalt	-	No transition point	-7.12	-7.23	-	-	-	-	0.06	-7.80	-8.83	-	-	-	-
					0.01	-7.43		-		-		0.08	-9.66		-		-	
					No transition point	-3.22		-		-		0.00	-5.02		-		-	
Honda	TRX500FM	TS57200	Asphalt	-	No transition point	-3.56	-3.67	-	-	-	-	No transition point	-4.08	-4.39	-	-	-	-
					No transition point	-4.24		-		-		No transition point	-4.07		-		-	
					0.14	-		0.86		-4.87		0.15	-		0.74		-3.48	
Yamaha	YFM450FAP Grizzly	TS57201	Asphalt	-	0.14	-	-	0.81	0.79	-5.01	-4.41	0.18	-	-	0.90	0.86	-2.34	-2.48
					0.15	-		0.71		-3.35		0.21	-		0.92		-1.63	
					0.15	-		1.57		-8.03		0.06	-8.50		-		-	
Polaris	Sportsman 450HO	TS57202	Asphalt	-	0.16	-	-	1.79	1.70	-7.70	-8.23	0.08	-8.29	-8.39	-	0.04	-	-7.97
					0.15	-		1.75		-8.97		0.10	-		0.04		-7.97	
					No transition point	-8.58		-		-		0.00	-9.14		-		-	
Suzuki	Kingquad 400ASI	TS57203	Asphalt	-	No transition point	-8.49	-8.61	-	-	-	-	No transition point	-7.89	-8.32	-	-	-	-
					No transition point	-8.75		-		-		0.03	-7.93		-		-	
					No transition point	-3.08		-		-		No transition point	-2.10		-		-	
Kawasaki	KVF300	TS57204	Asphalt	-	No transition point	-4.86	-4.22	-	-	-	-	No transition point	-4.31	-3.60	-	-	-	-
					No transition point	-4.71		-		-		No transition point	-4.40		-		-	
					0.11	-		0.13		-5.74		0.11	-		0.19		-8.40	
Kymco	MXU300	TS57205	Asphalt	-	0.11	-	-	0.16	0.15	-5.88	-5.61	0.13	-	-	1.12	0.55	-9.30	-8.97
					0.11	-		0.17		-5.22		0.11	-		0.34		-9.22	
					No transition point	-3.89		-		-		0.03	-1.83		-		-	
CF Moto	CF500	TS57206	Asphalt	-	No transition point	-5.73	-4.37	-	-	-	-	No transition point	-2.79	-2.20	-	-	-	-
					0.05	-3.49		-		-		0.07	-1.98		-		-	
					0.17	-		0.92		-2.96		0.01	-8.35		-		-	
Yamaha	Rhino 700	TS57207	Asphalt	-	0.19	-	-	1.28	1.37	-3.00	-3.31	0.02	-8.38	-8.72	-	-	-	-
					0.2	-		1.91		-3.97		0.04	-9.42		-		-	
					0.44	0.97		-		-		No transition point	2.11		-		-	
Kubota	RTV500	TS57208	Asphalt	-	0.39	-	0.97	1.06	1.18	-0.06	-0.13	No transition point	2.12	2.15	-	-	-	-
					0.36	-		1.31		-0.20		No transition point	2.23		-		-	
					No transition point	2.25		-		-		No transition point	5.74		-		-	
John Deere	Gator XUV825i	TS57209	Asphalt	-	No transition point	2.12	2.40	-	-	-	-	0.04	7.20	6.48	-	-	-	-
					No transition point	2.83		-		-		No transition point	6.49		-		-	
					No transition point	1.87		-		-		0.07	3.07		-		-	
Honda	Big red MUV700	TS57210	Asphalt	-	No transition point	2.28	1.96	-	-	-	-	No transition point	3.89	3.55	-	-	-	-
					0.07	1.74		-		-		0.04	3.70		-		-	
					No transition point	4.82		-		-		No transition point	4.88		-		-	
Tomcar	TM2	TS58278	Asphalt	-	0.02	5.24	5.04	-	-	-	-	No transition point	5.96	5.28	-	-	-	-
					No transition point	5.06		-		-		No transition point	5.01		-		-	
					0.15	-		0.24		-1.09		No transition point	-3.81		-		-	
Can-am	DS90X	TS57211	Asphalt	-	0.21	-	-	0.49	0.38	-0.92	-1.01	No transition point	-4.28	-3.92	-	-	-	-
					0.19	-		0.41		-1.03		No transition point	-3.67		-		-	
					No transition point	-5.38		-		-		No transition point	-7.90		-		-	
Yamaha	YFM250R Raptor	TS57212	Asphalt	-	No transition point	-4.94	-5.18	-	-	-	-	No transition point	-7.72	-7.99	-	-	-	-
					No transition point	-5.22		-		-		0.03	-8.35		-		-	
					0.34	-		2.97		-0.71		0.29	-		4.40		-2.69	
Honda	TRX700XX	TS57213	Asphalt	-	0.33	-	-	2.48	2.61	-0.77	-0.72	0.28	-	-	4.20	4.12	-2.97	-2.63
					0.33	-		2.38		-0.68		0.29	-		3.75		-2.25	

					Steering gradient - circle direction Left							Steering gradient - circle direction Right						
Vehicle make	Vehicle model	Specimen number	Surface	Additional Conditions	Steering gradient transition point (lateral acceleration g)	Steering gradient (°/g) between 0.1g & 0.4g lateral acceleration	Average steering gradient (°/g) between 0.1g & 0.4g lateral acceleration	Steering gradient (°/g) between 0.1g lateral acceleration & transition point	Average steering gradient (°/g) between 0.1g lateral acceleration & transition point	Steering gradient (°/g) between transition point & 0.4g lateral acceleration	Average steering gradient (°/g) between transition point & 0.4g lateral acceleration	Steering gradient transition point (lateral acceleration g)	Steering gradient (°/g) between 0.1g & 0.4g lateral acceleration	Average steering gradient (°/g) between 0.1g & 0.4g lateral acceleration	Steering gradient (°/g) between 0.1g lateral acceleration & transition point	Average steering gradient (°/g) between 0.1g lateral acceleration & transition point	Steering gradient (°/g) between transition point & 0.4g lateral acceleration	Average steering gradient (°/g) between transition point & 0.4g lateral acceleration
Honda	TRX250	TS57199	Asphalt	Front load	0.04	-10.92	-9.22	-	-	-	-	0.03	-7.80	-8.28	-	-	-	-
					No transition point	-7.49		-		-		0.06	-9.41		-		-	
					No transition point	-9.24		-		-		0.03	-7.63		-		-	
Honda	TRX250	TS57199	Asphalt	Rear load	0.05	-10.65	-11.70	-	-	-	-	0.11	-	-10.21	0.15	0.15	-9.22	-9.22
					0.06	-12.55		-		-		0.08	-9.90		-		-	
					0.01	-11.88		-		-		0.10	-10.51		-		-	
Honda	TRX250	TS57199	Asphalt	Front & rear load	0.08	-13.63	-12.59	-	-	-	-	0.08	-11.39	-11.90	-	-	-	-
					0.06	-12.33		-		-		0.08	-12.81		-		-	
					0.05	-11.80		-		-		0.07	-11.51		-		-	
Honda	TRX250	TS57199	Grass	-	0.03	-6.29	-6.95	-	-	-	-	No transition point	-8.09	-7.73	-	-	-	-
					No transition point	-7.22		-		-		No transition point	-6.45		-		-	
					No transition point	-7.33		-		-		No transition point	-8.63		-		-	
Honda	TRX250	TS57199	Grass	Front load	No transition point	-6.81	-6.55	-	-	-	-	0.01	-10.15	-9.57	-	-	-	-
					No transition point	-5.98		-		-		No transition point	-9.95		-		-	
					No transition point	-6.87		-		-		No transition point	-8.59		-		-	
Honda	TRX250	TS57199	Grass	Rear load	0.05	-9.59	-9.53	-	-	-	-	No transition point	-7.45	-8.36	-	-	-	-
					No transition point	-9.44		-		-		No transition point	-8.61		-		-	
					No transition point	-9.58		-		-		No transition point	-9.01		-		-	
Honda	TRX250	TS57199	Grass	Front & rear load	0.05	-9.27	-9.32	-	-	-	-	No transition point	-11.72	-9.64	-	-	-	-
					No transition point	-9.48		-		-		No transition point	-8.54		-		-	
					0.00	-9.21		-		-		No transition point	-8.67		-		-	
Honda	TRX250	TS57199+(	Asphalt	Quadbar CPD	0.06	-10.64	-10.34	-	-	-	-	0.09	-9.60	-9.12	-	-	-	-
					0.03	-10.25		-		-		0.08	-9.12		-		-	
					0.02	-10.12		-		-		0.07	-8.63		-		-	
Honda	TRX250	TS57199+(	Asphalt	Lifeguard CPD	0.05	-10.61	-10.72	-	-	-	-	0.09	-10.26	-9.80	-	-	-	-
					0.02	-10.48		-		-		0.09	-10.27		-		-	
					0.02	-11.07		-		-		0.10	-8.88		-		-	
Honda	TRX250	TS57199	Asphalt	Active riding, sideways	0.12	-	-	0.50	0.47	-6.01	-5.37	0.09	-4.44	-4.95	-	1.21	-	-5.24
					0.13	-		0.48		-4.61		0.08	-5.47		-		-	
					0.12	-		0.44		-5.51		0.16	-		1.21		-5.24	
Honda	TRX250	TS57199	Asphalt	Active riding, forwards	0.03	-7.51	-7.83	-	-	-	-	0.07	-9.37	-8.21	-	-	-	-
					No transition point	-7.45		-		-		0.07	-8.03		-		-	
					0.00	-8.53		-		-		0.07	-7.23		-		-	
Honda	TRX250	TS57199	Asphalt	Active riding, rearwards	0.03	-8.60	-8.70	-	-	-	-	0.07	-9.47	-9.56	-	-	-	-
					0.02	-8.43		-		-		0.08	-9.33		-		-	
					0.05	-9.08		-		-		0.09	-9.88		-		-	
Honda	TRX250	TS57199	Asphalt	Higher tyre pressures	No transition point	-5.30	-5.74	-	-	-	-	0.05	-5.62	-5.78	-	-	-	-
					No transition point	-5.39		-		-		0.08	-5.82		-		-	
					No transition point	-6.52		-		-		0.05	-5.91		-		-	
Honda	TRX250	TS57199	Asphalt	Alternative rider	-	-	-	-	-	-	-	0.08	-9.14	-8.45	-	-	-	-
					-	-		-		-		0.05	-7.72		-		-	
					-	-		-		-		0.08	-8.49		-		-	
Yamaha	YFM450FAP Grizzly	TS57201	Grass	-	0.12	-	-	0.32	0.44	-5.56	-5.30	0.14	-	-	1.02	1.04	-6.07	-4.29
					0.13	-		0.57		-4.56		0.24	-		0.92		-1.04	
					0.12	-		0.43		-5.78		0.15	-		1.19		-5.76	
Yamaha	YFM250R Raptor	TS57212	Grass	-	No transition point	-4.20	-4.06	-	-	-	-	No transition point	-6.54	-7.14	-	-	-	-
					No transition point	-4.25		-		-		No transition point	-7.69		-		-	
					No transition point	-3.74		-		-		No transition point	-7.18		-		-	

					Steering gradient - circle direction Left							Steering gradient - circle direction Right						
Vehicle make	Vehicle model	Specimen number	Surface	Additional Conditions	Steering gradient transition point (lateral acceleration g)	Steering gradient (°/g) between 0.1g & 0.4g lateral acceleration	Average steering gradient (°/g) between 0.1g & 0.4g lateral acceleration	Steering gradient (°/g) between 0.1g lateral acceleration & transition point	Average steering gradient (°/g) between 0.1g lateral acceleration & transition point	Steering gradient (°/g) between transition point & 0.4g lateral acceleration	Average steering gradient (°/g) between transition point & 0.4g lateral acceleration	Steering gradient transition point (lateral acceleration g)	Steering gradient (°/g) between 0.1g & 0.4g lateral acceleration	Average steering gradient (°/g) between 0.1g & 0.4g lateral acceleration	Steering gradient (°/g) between 0.1g lateral acceleration & transition point	Average steering gradient (°/g) between 0.1g lateral acceleration & transition point	Steering gradient (°/g) between transition point & 0.4g lateral acceleration	Average steering gradient (°/g) between transition point & 0.4g lateral acceleration
					No transition point	-6.32		-		-		No transition point	-4.48		-		-	
Kawasaki	KVF300	TS57204	Asphalt	Alternative rider	No transition point	-6.67	-6.68	-	-	-	-	No transition point	-4.24	-4.13	-	-	-	-
					No transition point	-7.04		-		-		No transition point	-3.69		-		-	
					0.1	-		0.01		-1.19		0.15	-		0.18		-0.94	
Honda	Big red MUV700	TS57210	Asphalt	Rear differential locked	0.19	-	-	0.37	0.41	-0.83	-1.04	0.1	-1.06	-1.06	-	0.31	-	-1.17
					0.23	-		0.84		-1.10		0.17	-		0.44		-1.40	
					0.16	-		0.19		-0.82		0.13	-		-0.03		0.46	
Honda	Big red MUV700	TS57210	Asphalt	Rear load	0.17	-	-1.12	0.12	0.15	-0.37	-0.60	0.18	-	-	-0.26	-0.21	0.83	0.65
					No transition point	-1.12		-		-		0.2	-		-0.34		0.67	
					No transition point	3.26		-		-		No transition point	2.77		-		-	
Honda	Big red MUV700	TS57210	Grass	-	No transition point	3.76	3.53	-	-	-	-	No transition point	5.20	3.99	-	-0.15	-	1.70
					No transition point	3.59		-		-		0.12	-		-0.15		1.70	
					0.12	-		-0.15		2.61		0.07	4.19		-		-	
Honda	Big red MUV700	TS57210	Grass	Rear load	0.07	1.49	2.31	-	-0.15	-	2.61	No transition point	2.13	2.69	-	-	-	-
					0.04	3.14		-		-		0.07	1.76		-		-	
					0.22	-		2.18		-3.28		0.07	-8.92		-		-	
Yamaha	Rhino 700	TS57207	Asphalt	Rear load	0.22	-	-	2.20	1.89	-3.21	-3.23	0.07	-9.73	-9.67	-	-	-	-
					0.19	-		1.28		-3.21		0.09	-10.37		-		-	
					0.13	-		0.21		-1.74		No transition point	-9.94		-		-	
Yamaha	Rhino 700	TS57207	Grass	-	0.16	-	-4.02	0.71	0.46	-2.86	-2.30	No transition point	-10.55	-10.17	-	-	-	-
					0.1	-4.02		-		-		No transition point	-10.02		-		-	
					0.21	-		0.73		-1.31		0.06	-10.21		-		-	
Yamaha	Rhino 700	TS57207	Grass	Rear load	0.22	-	-	0.95	0.95	-1.36	-1.48	0	-9.56	-9.97	-	-	-	-
					0.22	-		1.17		-1.77		0.04	-10.15		-		-	

3. Lateral transient response – result summary

Vehicle make	Vehicle model	Specimen number	Surface	Additional Conditions	Lateral transient response time (s) Left	Left average	Right	Right average
Honda	TRX250	TS57199	Asphalt	-	0.12	0.12	0.15	0.14
					0.13		0.14	
					0.12		0.12	
Honda	TRX500FM	TS57200	Asphalt	-	0.16	0.16	0.16	0.17
					0.17		0.17	
					0.15		0.18	
Yamaha	YFM450FAP Grizzly	TS57201	Asphalt	-	0.14	0.14	0.13	0.13
					0.14		0.12	
					0.14		0.14	
Polaris	Sportsman 450HO	TS57202	Asphalt	-	0.13	0.13	0.13	0.13
					0.11		0.14	
					0.16		0.12	
Suzuki	Kingquad 400ASI	TS57203	Asphalt	-	0.16	0.17	0.14	0.15
					0.17		0.14	
					0.17		0.17	
Kawasaki	KVF300	TS57204	Asphalt	-	0.12	0.13	0.14	0.13
					0.13		0.13	
					0.13		0.13	
Kymco	MXU300	TS57205	Asphalt	-	0.11	0.11	0.08	0.09
					0.12		0.09	
					0.11		0.09	
CF Moto	CF500	TS57206	Asphalt	-	0.25	0.23	0.18	0.17
					0.24		0.17	
					0.19		0.17	
Yamaha	Rhino 700	TS57207	Asphalt	-	0.23	0.29	0.33	0.28
					0.28		0.25	
					0.36		0.25	
Kubota	RTV500	TS57208	Asphalt	-	0.15	0.18	0.20	0.20
					0.19		0.19	
					0.21		0.20	
John Deere	Gator XUV825i	TS57209	Asphalt	-	0.26	0.26	0.30	0.28
					0.26		0.27	
					0.27		0.27	
Honda	Big red MUV700	TS57210	Asphalt	-	0.23	0.25	0.35	0.28
					0.24		0.29	
					0.27		0.21	
Tomcar	TM2	TS58278	Asphalt	-	0.22	0.22	0.16	0.17
					0.23		0.17	
					0.21		0.18	
Can-am	DS90X	TS57211	Asphalt	-	0.15	0.15	0.14	0.15
					0.17		0.15	
					0.13		0.15	
Yamaha	YFM250R Raptor	TS57212	Asphalt	-	0.15	0.15	0.19	0.20
					0.15		0.19	
					0.14		0.22	
Honda	TRX700XX	TS57213	Asphalt	-	0.10	0.10	0.17	0.14
					0.10		0.13	
					0.10		0.12	

Vehicle make	Vehicle model	Specimen number	Surface	Additional Conditions	Lateral transient response time (s) Left	Left average	Right	Right average
Honda	TRX250	TS57199	Asphalt	Front load	0.14	0.16	0.13	0.13
					0.15		0.13	
					0.20		0.13	
Honda	TRX250	TS57199	Asphalt	Rear load	0.18	0.21	0.23	0.20
					0.25		0.18	
					0.20		0.19	
Honda	TRX250	TS57199	Asphalt	Front & rear load	0.14	0.16	0.27	0.23
					0.15		0.22	
					0.20		0.19	
Honda	TRX250	TS57199	Grass	-	0.25	0.24	0.19	0.27
					0.24		0.30	
					0.22		0.31	
Honda	TRX250	TS57199	Grass	Front load	0.13	0.14	0.17	0.18
					0.15		0.23	
					0.13		0.15	
Honda	TRX250	TS57199	Grass	Rear load	0.39	0.34	0.40	0.40
					0.39		0.45	
					0.23		0.34	
Honda	TRX250	TS57199	Grass	Front & rear load	0.21	0.22	0.32	0.30
					0.19		0.32	
					0.25		0.25	
Honda	TRX250	TS57199+CPD1	Asphalt	Quadbar CPD	0.12	0.13	0.16	0.16
					0.15		0.16	
					0.13		0.15	
Honda	TRX250	TS57199+CPD2	Asphalt	Lifeguard CPD	0.17	0.15	0.15	0.16
					0.15		0.17	
					0.13		0.15	
Honda	TRX250	TS57199	Asphalt	Active riding, sideways	0.18	0.25	0.30	0.25
					0.18		0.25	
					0.39		0.20	
Honda	TRX250	TS57199	Asphalt	Active riding, forwards	0.14	0.14	0.13	0.12
					0.13		0.12	
					0.14		0.12	
Honda	TRX250	TS57199	Asphalt	Active riding, rearwards	0.15	0.18	0.16	0.18
					0.19		0.19	
					0.19		0.19	
Honda	TRX250	TS57199	Asphalt	Higher tyre pressures	0.10	0.10	0.10	0.11
					0.10		0.12	
					0.10		0.11	
Honda	TRX250	TS57199	Asphalt	Alternative rider	0.10	0.12	0.16	0.18
					0.13		0.23	
					0.12		0.15	
Yamaha	YFM450FAP Grizzly	TS57201	Grass	-	0.31	0.37	0.31	0.25
					0.42		0.27	
					0.38		0.16	
Yamaha	YFM250R Raptor	TS57212	Grass	-	0.22	0.34	0.52	0.47
					0.47		0.46	
					0.32		0.42	

Vehicle make	Vehicle model	Specimen number	Surface	Additional Conditions	Lateral transient response time (s) Left	Left average	Right	Right average
Kawasaki	KVF300	TS57204	Asphalt	Alternative rider	0.12	0.14	0.15	0.14
					0.13		0.14	
					0.16		0.13	
Honda	Big red MUV700	TS57210	Asphalt	Rear differential locked	0.21	0.22	0.24	0.23
					0.22		0.23	
					0.22		0.22	
Honda	Big red MUV700	TS57210	Asphalt	Rear load	0.21	0.21	0.23	0.22
					0.22		0.21	
					0.20		0.21	
Honda	Big red MUV700	TS57210	Grass	-	0.37	0.47	0.38	0.37
					0.61		0.32	
					0.43		0.40	
Honda	Big red MUV700	TS57210	Grass	Rear load	0.32	0.40	0.37	0.36
					0.41		0.37	
					0.46		0.34	
Yamaha	Rhino 700	TS57207	Asphalt	Rear load	0.37	0.28	0.45	0.42
					0.20		0.37	
					0.27		0.44	
Yamaha	Rhino 700	TS57207	Grass	-	0.39	0.43	0.49	0.47
					0.38		0.56	
					0.52		0.35	
Yamaha	Rhino 700	TS57207	Grass	Rear load	0.28	0.35	0.44	0.48
					0.36		0.44	
					0.40		0.56	

4. Bump obstacle perturbation – result summary

Vehicle make	Vehicle model	Specimen number	Average resultant acceleration (g) Left bump	Left bump average	Right bump	Right bump average
Honda	Fourtrax TRX250	TS57199	2.59	2.45	2.84	2.78
			2.27		2.85	
			2.48		2.66	
Honda	Foreman TRX500FM	TS57200	2.17	2.14	2.10	2.14
			2.05		2.04	
			2.20		2.27	
Yamaha	Grizzly YFM450FAP	TS57201	1.76	1.76	1.80	1.93
			1.84		2.06	
			1.68		1.93	
Polaris	Sportsman 450HO	TS57202	1.81	1.93	1.82	1.72
			1.99		1.59	
			2.00		1.76	
Suzuki	Kingquad 400ASI	TS57203	1.88	2.15	2.23	2.22
			2.33		2.20	
			2.23		2.23	
Kawasaki	KVF300	TS57204	2.55	2.55	3.04	2.97
			2.56		2.91	
			2.55		2.96	
Kymco	MXU300	TS57205	2.30	2.28	2.12	2.13
			2.21		2.21	
			2.32		2.07	
CF Moto	CF500	TS57206	1.66	1.57	1.77	1.80
			1.58		1.84	
			1.47		1.78	
Can-am	DS90X	TS57211	2.58	2.62	3.36	3.48
			2.61		3.66	
			2.68		3.41	
Yamaha	Raptor YFM250R	TS57212	3.21	3.15	3.11	3.11
			3.19		3.02	
			3.04		3.19	
Honda	TRX700XX	TS57213	1.93	1.89	2.05	2.05
			1.74		2.03	
			1.99		2.08	

Vehicle make	Vehicle model	Specimen number	Average resultant acceleration (g) Left bump	Left bump range	Right bump	Right bump range
Honda	Fourtrax TRX250	TS57199	2.59	0.32	2.84	0.19
			2.27		2.85	
			2.48		2.66	
Honda	Foreman TRX500FM	TS57200	2.17	0.15	2.10	0.23
			2.05		2.04	
			2.20		2.27	
Yamaha	Grizzly YFM450FAP	TS57201	1.76	0.16	1.80	0.26
			1.84		2.06	
			1.68		1.93	
Polaris	Sportsman 450HO	TS57202	1.81	0.19	1.82	0.23
			1.99		1.59	
			2.00		1.76	
Suzuki	Kingquad 400ASI	TS57203	1.88	0.45	2.23	0.03
			2.33		2.20	
			2.23		2.23	
Kawasaki	KVF300	TS57204	2.55	0.01	3.04	0.13
			2.56		2.91	
			2.55		2.96	
Kymco	MXU300	TS57205	2.30	0.11	2.12	0.14
			2.21		2.21	
			2.32		2.07	
CF Moto	CF500	TS57206	1.66	0.19	1.77	0.07
			1.58		1.84	
			1.47		1.78	
Can-am	DS90X	TS57211	2.58	0.10	3.36	0.30
			2.61		3.66	
			2.68		3.41	
Yamaha	Raptor YFM250R	TS57212	3.21	0.17	3.11	0.17
			3.19		3.02	
			3.04		3.19	
Honda	TRX700XX	TS57213	1.93	0.25	2.05	0.05
			1.74		2.03	
			1.99		2.08	

Appendix D
Instrument Response Data

Intentionally not added to this report as file is large (285 pages)

Appendix E
Test specimen details

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

1. Vehicle details and specimen numbers

Vehicle make	Honda	Honda	Yamaha	Polaris	Suzuki	Kawasaki	Kymco	CF Moto	Can-am	Yamaha	Honda	Yamaha	Kubota	John Deere	Honda	Tomcar
Vehicle model	Fourtrax TRX250	Foreman TRX500FM	Grizzly YFM450FAP	Sportsman 450HO	Kingquad 400ASI	KVF300	MXU300	CF500	DS90X	Raptor YFM250R	TRX700XX	Rhino YXR 700	RTV500	Gator XUV825i	Big Red MUV700	TM-2
Test specimen number	TS57199	TS57200	TS57201	TS57202	TS57203	TS57204	TS57205	TS57206	TS57211	TS57212	TS57213	TS57207	TS57208	TS57209	TS57210	TS58248
Vehicle type	Quad - agricultural	Quad - agricultural	Quad - agricultural	Quad - agricultural	Quad - agricultural	Quad - agricultural	Quad - agricultural	Quad - agricultural	Quad - Sport	Quad - Sport	Quad - Sport	SSV	SSV	SSV	SSV	SSV
Engine capacity (cc)	229.2	475.3	421	455	376	271	270	493	89	249	686	686	456	812	675	1000
Driven wheels	rear	4WD (switchable)	4WD (switchable)	4WD (switchable)	rear	rear	rear	4WD (switchable)	rear	rear	rear	4WD (switchable)	4WD (switchable)	4WD (switchable)	4WD (switchable)	rear
Rear differential	locked	locked	locked	locked	locked	locked	locked	locked	locked	locked	locked	locked	open/locked (switchable)	open/locked (switchable)	open/locked (switchable)	open/locked (switchable)
Seat type	saddle	saddle	saddle	saddle	saddle	saddle	saddle	saddle	saddle	saddle	saddle	bucket	bench	bucket	bucket	bucket
Tyres front	Maxxis M903	Maxxis M975	Cheng Shin C 828	Carlisle AT489	Dunlop KT121	Maxxis	Maxxis	Innova mud gear lite	Klaw MXR	Dunlop KT201	Dunlop KT363	Maxxis	OTR 350 Mag off road	CST ANCLA	Maxxis bighorn	Deestone
Tyres rear	Maxxis M9804	Maxxis M978	Cheng Shin C 828	Carlisle AT489	Dunlop KT405	Maxxis	Maxxis	Innova mud gear lite	Klaw MXR	Dunlop KT205A	Dunlop KT378A	Maxxis	OTR 350 Mag off road	CST ANCLA	Maxxis bighorn	Deestone swampwitch
Tyre size front	AT22x7-11	AT25x8-12	AT25x8-12	AT25x8-12	AT25x8-12	AT22x7-10	AT22x7-10	AT25x8-12	AT20x6-10	AT20x7-10	AT21x7-10	25x8-12	24x9-12	26x9-12	25x10-12	AT25x8-12
Tyre size rear	AT22x10-9	AT25x10-12	AT25x10-12	AT25x10-12	AT25x10-12	AT22x10-10	AT22x10-10	AT25x10-12	AT18x10-8	AT19x10-9	AT22x9-11	25x10-12	24x11-12	26x11-12	25x10-12	26x12-12
Manufacturer recommended tyre pressure front (kPa)	20	30	25	34.5	32.5	32	25 to 32	35	25 to 35	27.5	35	70	100	97	70	105
Manufacturer recommended tyre pressure rear (kPa)	20	30	25	34.5	30	24	25 to 32	30	25 to 35	27.5	42.5	98	100	97 to 124	120	140
Fuel tank capacity (l)	9.1	15	15	16	16	12	12.5	19	6	9	11.4	30	20	20	30	26
Seating capacity	1	1	1	1	1	1	1	2	1	1	1	2	2	2	2	2
Vehicle width (mm)	1035	1205	1093	1220	1200	1080	1050	1170	1110	1070	1165	1385	1390	1500	1626	1780
Vehicle track width - front (mm)	795	930	860	1002	880	850	810	960	950	810	1000	1130	1016	1280	1290	1520
Vehicle track width - rear (mm)	775	925	860	964	900	830	780	860	845	825	930	1096	1041	1304	1296	1460
Vehicle length (mm)	1905	2127	1993	2110	2160	1915	1810	2120	1520	1625	1815	2885	2690	2870	2913	2820
Vehicle wheelbase (mm)	1131	1281	1233	1283	1270	1165	1160	1290	1024	1110	1260	1910	1800	2010	1922	2050
Front cargo capacity (kg)	15	30	40	41	30	20	20	20	0	0	0	0	0	0	0	0
Rear cargo capacity (kg)	30	60	80	82	60	30	30	40	0	0	0	181	200	454	454	200
Maximum vehicle payload capacity (kg)	175	220	210	220	172	164	165	180	70	100	110	367	430	635	767	400
Unladen kerb mass (kg)	199	293	289.5	327	275.5	246	229	371.5	146.5	152.5	230	552.9	621.2	776.1	646.9	766.2
Distance of unladen COG behind front axle (mm)	568	608	571	657	615	554	570	606	475	542	668	1062	1081	1176	973	1333
Distance of unladen COG from vehicle centreline (mm)	6 right	8 right	2 left	7 right	7 right	3 left	5 left	5 left	1 left	4 right	2 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 F
Test Photographs

Appendix Prepared by: Drew Sherry

Appendix Checked by: Ross Dal Nevo

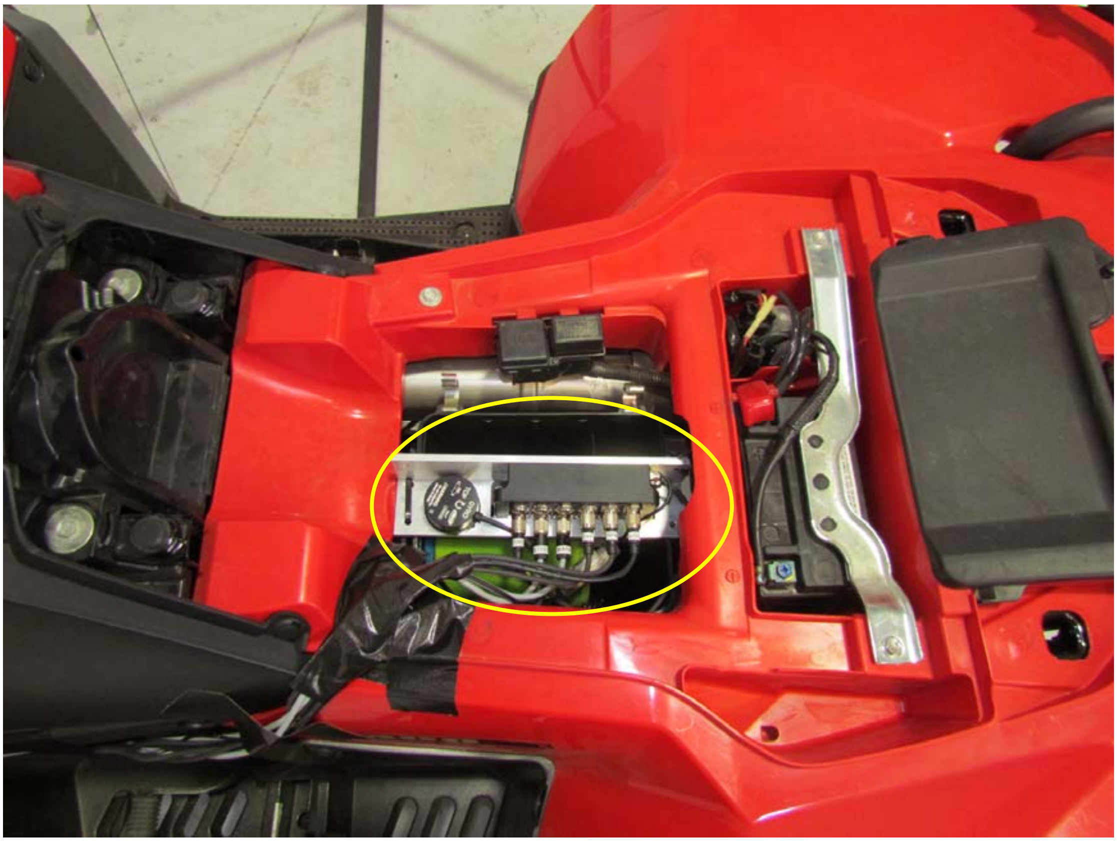
1. Test equipment photographs – Circular driving behaviour and Lateral transient response

Quad bike with outrigger fitted (typical installation)

Quad bike with outrigger fitted (typical installation)

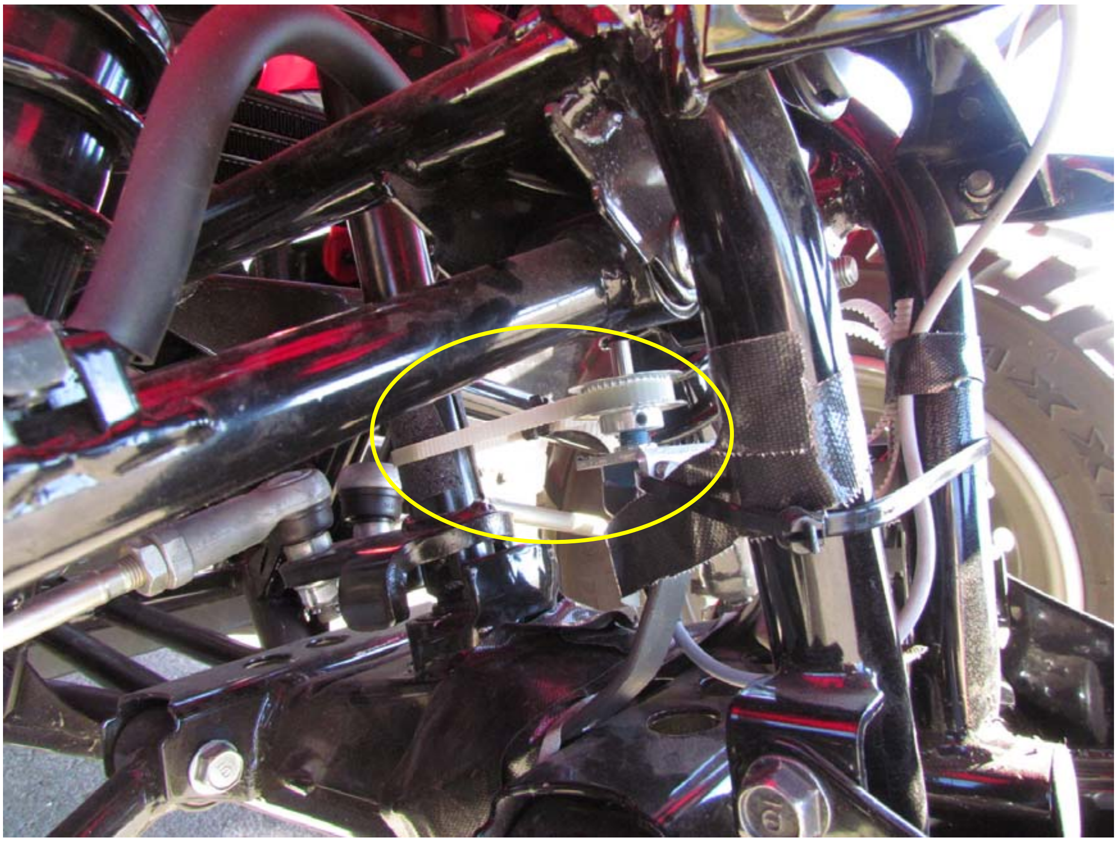
Quad bike with outrigger fitted (typical installation)


Quad bike with outrigger fitted (typical installation)



Data acquisition system, accelerometers and rate gyro installed close to COG (typical installation)

Distance measurement lasers (typical installation)


Steering potentiometer (typical installation)

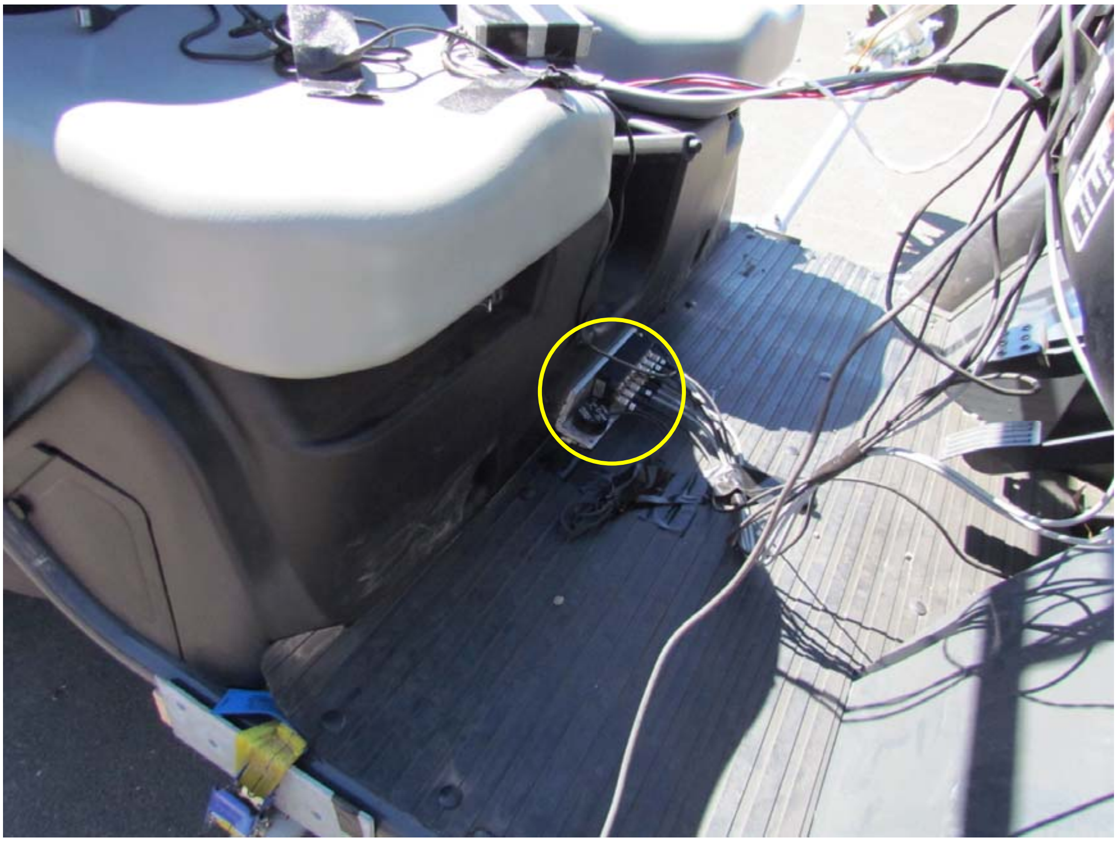

GPS antennae, battery and ancillary equipment (typical installation)

Side by Side Vehicle with outrigger fitted (typical installation)

Side by Side Vehicle with outrigger fitted (typical installation)

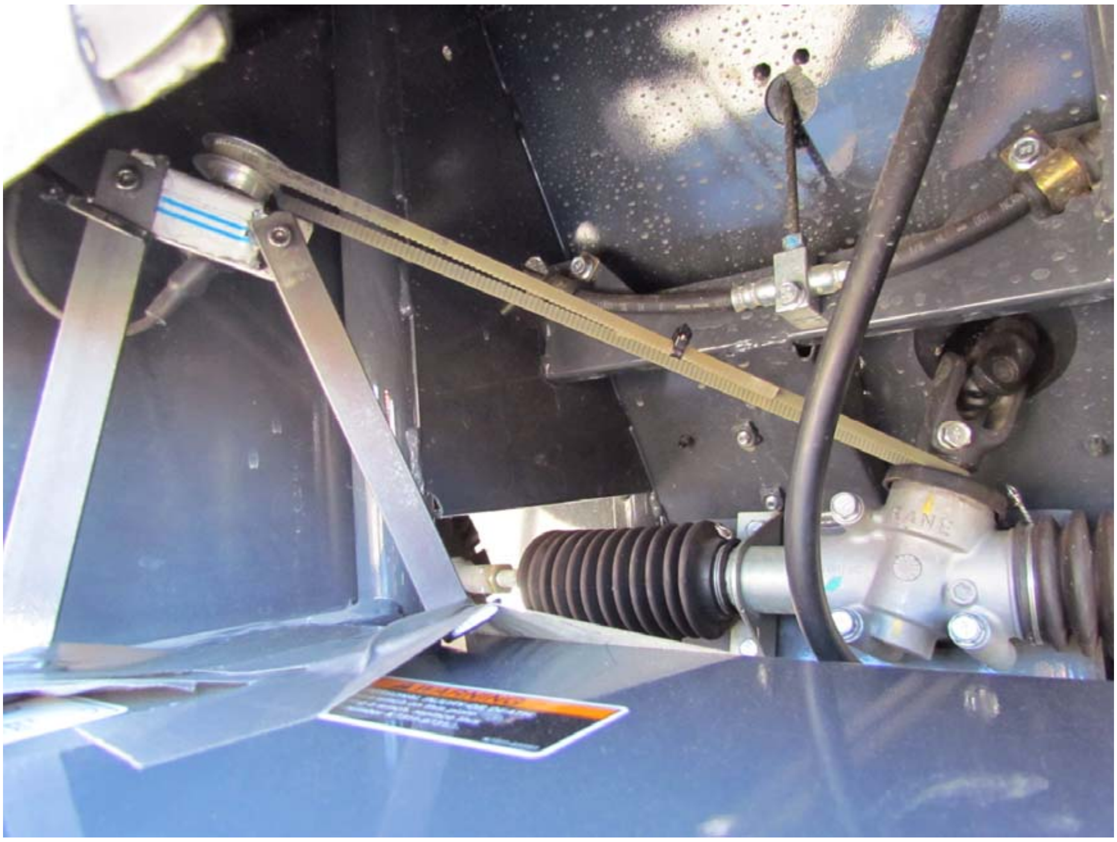
Side by Side Vehicle with outrigger fitted (typical installation)

Side by Side Vehicle with outrigger fitted (typical installation)



Data acquisition system, accelerometers and rate gyro installed close to COG (typical installation)

Distance measurement lasers (typical installation)



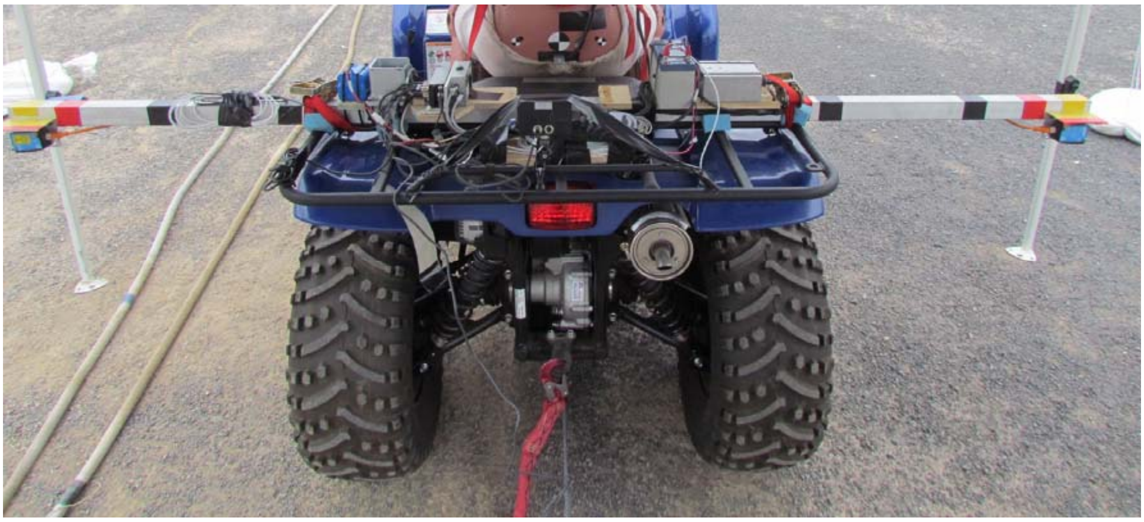
Steering potentiometer (typical installation)

GPS antennae and ancillary equipment (typical installation)

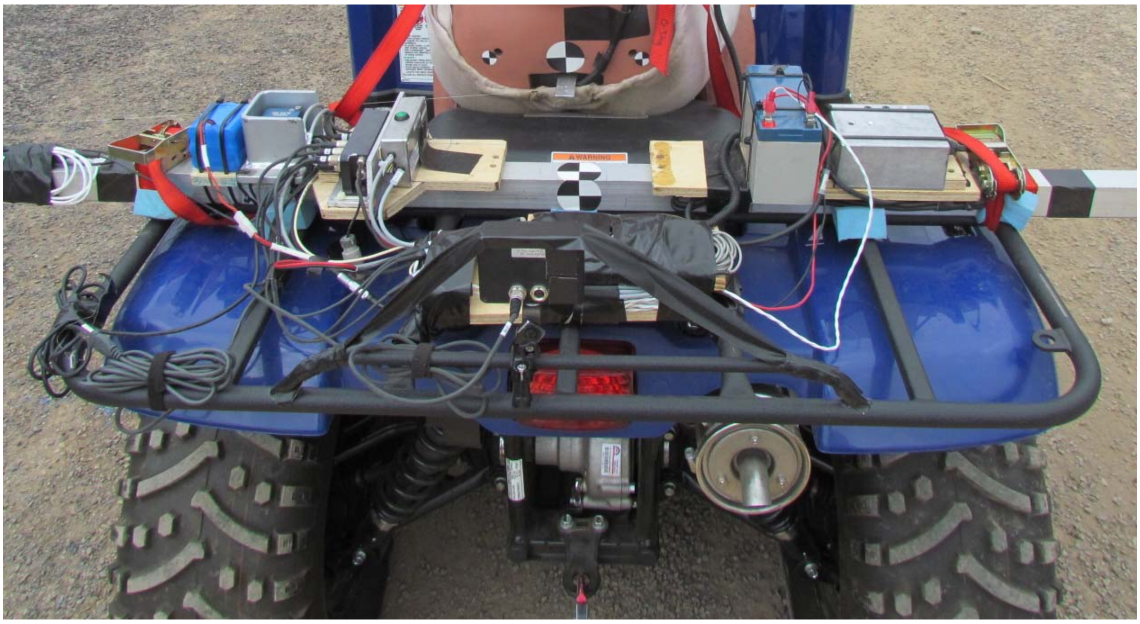
Test site – asphalt

Test site - grass

2. Test equipment photographs – Bump obstacle perturbation



Data acquisition system and instruments (typical installation)



Data acquisition system and instruments (typical installation)

Bump obstacle

Bump obstacle (semi-circular, 150mm high)

3. Vehicle photographs

Honda Fourtrax TRX250 (TS57199)

Honda Fourtrax TRX250 (TS57199)

Honda Foreman TRX500FM (TS57200)

Honda Foreman TRX500FM (TS57200)

Yamaha Grizzly YFM450FAP (TS57201)

Yamaha Grizzly YFM450FAP (TS57201)

Polaris Sportsman 450HO (TS57202)

Polaris Sportsman 450HO (TS57202)

Suzuki Kingquad 400ASI (TS57203)

Suzuki Kingquad 400ASI (TS57203)

Kawasaki KVF300 (TS57204)

Kawasaki KVF300 (TS57204)

Kymco MXU300 (TS57205)

Kymco MXU300 (TS57205)

CF Moto CF500 (TS57206)

CF Moto CF500 (TS57206)

CanAm DS90X (TS57211)

CanAm DS90X (TS57211)

Yamaha Raptor YFM250R (TS57212)


Yamaha Raptor YFM250R (TS57212)

Honda TRX700XX (TS57213)

Honda TRX700XX (TS57213)

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)

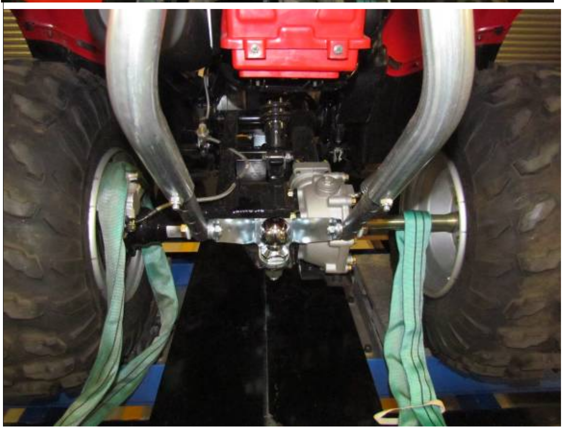
Honda Big Red MUV700 (TS57210)

Tomcar TM-2 (TS58278)

Tomcar TM-2 (TS58278)

4. Crush Protection Device (CPD) photographs

QB Industries Quadbar



Typical Quadbar installation

Ag-TECH Industries Lifeguard

Typical Lifeguard installation

5. Test setup photographs (load configurations)

Typical quad bike setup – no load

Typical quad bike setup - front load

Typical quad bike setup - rear load

Typical quad bike setup – front and rear load

Typical quad bike setup – Quadbar CPD

Typical quad bike setup – Lifeguard CPD

Typical Side by Side Vehicle setup – no load

Typical Side by Side Vehicle setup – rear load

6. Test snapshots – Circular driving behaviour

Typical quad bike Circular driving behaviour test (G130449)

Typical quad bike Circular driving behaviour test (G130449) – rear wheel lifted

Typical quad bike Circular driving behaviour test (G130449) – both wheels lifted

7. Test snapshots – Lateral transient response

Typical quad bike Lateral transient response test (G130455)

8. Test snapshots – Bump obstacle perturbation

Typical quad bike Bump obstacle perturbation test (G130917)

Appendix G
Instrument details

Appendix Prepared by: Drew Sherry

Appendix Checked by: Ross Dal Nevo

1. Instrument details

Instrument	Manufacturer	Model	Serial number
Yaw rate gyroscope	Aim sportsystems	5-3	X055NGYM30
Triaxial accelerometer	Aim sportsystems	EVO4 internal	1802601
GPS velocity	Aim sportsystems	EVO4 internal	1802601
Steering potentiometer (quad bikes)	Aim sportsystems	5G	X05SNST
Steering potentiometer (SSV's)	First Mark	14CB1-2897	3045
Measurement laser (left)	Sick	DT35-B15251	13300189
Measurement laser (right)	Sick	DT35-B15251	13300087
Anthropomorphic Test Device	FTSS	HIII 95%ile	275
Pelvis accelerometer (x)	Endevco	7264B-500	B10440
Pelvis accelerometer (y)	Endevco	7264B-500	B10513
Pelvis accelerometer (z)	Endevco	7264B-500	B10296
DTS slice data acquisition unit	DTS	Slice base	BA00063
DTS slice data acquisition unit	DTS	Slice bridge	BR00042
DTS slice data acquisition unit	DTS	Slice bridge	BR00296