Part 1:

STATIC STABILITY TEST RESULTS

REPORT 1

by

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

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Disclaimer

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

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

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1 Executive Summary

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.

The Heads of Workplace Safety Authorities (HWSA) has identified Quad bike safety to be a major issue on farms in Australia and New Zealand. They state that "*In Australia, more than 64 per cent of quad bike deaths occur on farms and in the last 10 years there have been 130 quad bike fatalities across the country. In New Zealand, five people (on average) are killed on farms and over 845 injuries reported each year*."

In his most recent study of Australian fatalities involving Quad bikes in the 12 year period 2001 to 2012, Lower (2013) identified:

- over 170 fatal cases, representing approximately 14 fatalities per year;
- approximately 60% of all Quad bike related deaths involved rollover;
- over 89% of rollover deaths occurred on farms.

Further detailed analysis has also identified crush and asphyxiation as being one of the injury mechanisms occurring in Quad bikes fatal rollover crashes that is of concern to workplace Work Health and Safety regulators and farmers. It has been advocated by some groups that to prevent such injuries, Crush Protection Devices (CPDs) be fitted such as the Quadbar and Lifeguard fixtures (described in the body of the report). Such devices are referred to in this report more generally as Operator Protection Devices (OPDs).

HWSA and the Quad bike Industry[1] supported Working Group developed a strategy aimed at reducing fatalities and injuries from Quad bike use on farms in a work setting. Part 7 of that Strategy document was 'Design'. This related to the aim to 'critically consider engineering and design features' for improved vehicle stability, and improved crashworthiness including Operator Protection Devices (and including retrofit of other safety accessories).

This Project is also aimed at addressing Part 7 of the Strategy (Design) for improving the safety of Quad bikes, in the farm environment. This is being done through the application of a Quad bike and Side by Side Vehicle Static Stability, Dynamic Handling and Rollover Crashworthiness Star Rating system (ATVAP: Australian Terrain Vehicle Assessment Program).

The use of a Star Rating system to inform consumers has been widely used and accepted by the general public, stakeholders and much of Industry. Examples include Star Ratings for white goods product energy efficiency, water efficiency (dishwashers, washing machines, etc.), consumer financial products, and for vehicles the very successful Australasian New Car Assessment Program (ANCAP), e.g. 'Stars On Cars' for vehicle safety. Indeed, ANCAP has been a catalyst for and helped promote large technological safety advances that have delivered major safety benefits in terms of reduced community trauma in the case of road vehicles.

It is hoped that ATVAP will provide similar benefits for consumers and workplace plant managers. The objective is to introduce a robust, test based rating system, in order to provide workplace and consumer based incentives for informed, safer and appropriate vehicle purchase (highlighting 'Fit For Purpose' criteria), and at the same time generate corresponding incentives and competition amongst the Quad bike and Side by Side Vehicle (SSV) Industry for improved designs and models.

The bulk of the Project has been funded by the WorkCover Authority of New South Wales (Australia) with support by the State Government of New South Wales (NSW). Some additional funding was also provided by the ACCC to include selected recreational Quad bikes into the test matrix.

The Quad Bike Performance Project (QBPP) commenced in September 2012 and the last series of testing (Rollover Crashworthiness) was completed by around June 2014.

The QBPP Project consists of three parts: Part 1 focusses on Static Stability (Report 1); Part 2 focusses on Dynamic Handling (Report 2); Part 3 focusses Rollover Crashworthiness (Report 3). There is a fourth report (Report 4) which is titled Final Project Summary Report: Quad Bike Performance Project Test Results, Conclusions and Recommendations. There is also a Supplemental Report that presents a summary of the 'Examination and Analysis of Quad Bike and Side By Side Vehicle (SSV) Fatalities and Injuries' carried out by McIntosh and Patton (2014a) and Mitchell (2014) and some further analysis by the co-Authors Grzebieta, Rechnitzer and Simmons.

This report presents the results of Part 1, i.e. static stability and thus rollover resistance characteristics of the Quad bike and Side by Side Vehicles (SSVs), as rollover (lateral roll, rear pitch roll and forward pitch roll) has been identified from the fatality data as a dominant crash mode and injury causation mechanism in the workplace. The entire testing program (Parts 1 to 3) was undertaken by the NSW Roads and Maritime Services Crashlab test laboratory facility in Sydney, NSW, Australia.

The test program had several major components:

1. The selection and purchase of 16 new representative production Quad bikes and Side-by-Side Vehicles shown in Table 1, and set out in the Crashlab test report (Attachment 2). Details of how the vehicles were selected are explained in Section 3.1.1.
2. Testing also included a prototype Quad bike (17th vehicle). 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 or other reports. 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.

3. Biomechanics injury analysis based on Quad bike and Side by Side Vehicle (SSV) injury data obtained from the United States of America (US) Consumer Product Safety Commission (CPSC) and the Australian National Coronial Information System (NCIS). Further detailed analysis and identification of injury mechanisms related to Quad bike and SSV fatal crashes, particularly rollover, and especially related to crush and asphyxiation were carried out. This in turn formed the basis of the development of related crashworthiness test methods. This task was not completed until late in the project, mainly as a result of delays in obtaining detailed Coronial case files which was beyond the control of the Authors. This had a knock on effect in the timing of the final delivery of all reports;

4. Series of Static Stability tests for lateral rollover and forward and rearward pitch rollover, based on tilt table tests with and without a rider (95^{th} % adult male Hybrid III Anthropomorphic Crash Test Dummy (ATD)), and with combinations of maximum cargo loads on the front and rear. Effects of a selected sample of operator protection type devices (OPDs) on Static Stability were also tested (This report: see Table 2 and Attachment 2);

5. Establishment of Static Stability indices for the selected Quad bike and SSV models (this report);

6. Series of Dynamic Handling tests. Tests included the ISO 4138:2012 Passenger Cars - Steady State Circular Driving and the ISO 7401:2011 Road Vehicles - Lateral transient response – open loop test methods, both modified for a Quad bike and a SSV. An obstacle perturbation test (simulating riding one side over a rock like object) was also included. Components of these tests complement the Static Stability evaluation. The results form part of the ATVAP rating for Dynamic Handling and incorporation into the overall vehicle Static Stability, Dynamic Handling and Rollover Crashworthiness Star Rating. Improvements in Quad bike and SSV handling has been suggested by authors such as Roberts (2009) and others as being a practical means to reduce crash and rollover risk;

7. Series of crashworthiness tests related to lateral rollover and front and rear pitch rollover. The tests are based on the outcomes from the injury analysis of CPSC and NCIS data and identification of rollover related injury mechanisms;

8. Development of a Static Stability, Dynamic Handling and Rollover Crashworthiness Star Rating system, Australian Terrain Vehicle Assessment Program (ATVAP), that combines the assessments of all three Parts, namely rollover Static Stability, Dynamic Handling and Rollover Crashworthiness components, into a 5 star consumer rating system.

The sixteen production vehicles selected for testing included: 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. The three sports/recreational Quad bikes were added to the project and funded by the Australian Competition and Consumer Commission (ACCC). Quad bike vehicles, often called All-Terrain Vehicles (ATVs) particularly in the USA, are four-wheeled vehicles designed so that the rider straddles the vehicle and controls it with a handlebar arrangement, similar to a two wheel motor-cycle. Side by Side Vehicles (SSVs) are designed so that a rider is seated in the vehicle and controls it with a steering wheel, similar to how a driver sits in a small car. SSVs are also designed so a passenger can sit alongside the driver (hence the name Side by Side Vehicle).

In Australia, it is estimated that there were approximately 270,000 Quad bikes and SSVs in use in 2010. This compares to an estimated 80,000 Quad bikes and SSVs in use in New Zealand agriculture in 2010 and an estimated 10 million Quad bikes and SSVs in use by 16 million individuals in 2008 in the United States (US).

SSVs are increasingly being used on farms and workplaces in place of Quad bikes, and are part of the 'Fit For Purpose' vehicle selection being promoted in a number of cases by the Quad bike Industry groups.

It was for this reason, and the recognition that improved Quad bike rollover safety may well require either an alternative vehicle or additional requirements to simply fitting of OPDs (Operator Protection Devices), that this project was expanded to include SSVs and not only Quad bikes. The test results clearly demonstrate that the inclusion of SSVs has proven to be most valuable and significant, providing a much needed context and relative Static Stability Indices to compare Quad bike Static Stability values against. Moreover, it was clear from the outset that OPDs do not prevent rollovers and in some circumstances may adversely affect rollover resistance. However, the effectiveness of OPDs in terms of injury prevention is assessed in Part 3 (focussing on Rollover Crashworthiness).

The 17 vehicles tested (16 production vehicles and one prototype Quad bike) are set out in Table 1 in the body of this report. Test vehicle specification details are provided in Appendix D of the Crashlab report (see Attachment 2).

To measure the effects on Quad bike static stability when OPDs are attached, tests were carried out with three different model OPDs (see Table 2) fitted to the 8 'work' Quad bikes. The OPDs were not able to be fitted to the Sports/Rec Quad bikes, as they had no practical provisions for mounting these units. None of the units had any manufacturer 'approved' mounting points. Manufacturers state that they do not support the fitment of OPDs to Quad bikes[2].

Fundamental engineering and scientific principles, as well as universal experiential knowledge, recognises that stability is an essential criterion for systems whether stationary

[2] http://www.fcai.com.au/news/news/all/all/311/atv-industry-opposes-rollover-devices-on-safety-grounds

or mobile. The consequences of vehicle tip over or rollover are well known in terms of fatal and serious injury risk.

The defining characteristics for static stability are all very similar, and of course obey the laws of physics and the actions of bodies under the force of gravity. Essentially a body, to not tip over when stationary, must have a 'footprint' large enough to provide an opposing static moment to overcome any lateral overturning forces 'acting' on it. In other words, when stationary the vehicle is in 'static equilibrium'. For a moving four wheel vehicle the resulting stability of the vehicle is also a function of its dynamic stability characteristics which are also dependent on its suspension and steering characteristics. Dynamic stability is covered in Part 2 of this project.

For a vehicle, that means that the overturning forces acting at the height of the centre of gravity (CoG) such as downward gravitational force on a slope, or centripetal acceleration for a vehicle in motion around a curve, can be resisted by the vehicle's weight acting vertically through its CoG about the point of overturning (i.e. the base width, or wheel track/ wheel base).

For vehicles, two key parameters affect lateral tip-over or rollover static stability: track width (distance to wheel centres) and centre of gravity height, specifically the ratio of CoG height to half the track width. As an axiomatic generalisation, the wider the track width and the lower the CoG height, the more statically stable (against rollover) a vehicle is.

While other variables such as suspension design, and handling do affect the lateral acceleration which may result in a rollover (i.e. increase or decrease the lateral acceleration required for rollover), the principal static stability characteristics for a vehicle are constrained within the vehicle's fundamental geometric properties of CoG height (and how this varies with any load), wheel base and track width.

The USA's National Highway Traffic Safety Administration (NHTSA) selected Static Stability Factor (SSF) as an appropriate metric for light vehicle rollover resistance as a universally accepted dynamic test was not developed at that time. The SSF is a common metric used to define light passenger vehicle rollover resistance, and is defined as one half the average front and rear track width divided by the total vehicle CoG height. The SSF is fundamentally related to and derived from the physics relating to vehicle steady state stability – both on a slope (stationary or moving) and in turning manoeuvres (circular motion).

The lower the SSF number, the lower the vehicle's resistance is to roll over if the applied side force is sufficiently high, for example due to a vehicle travelling around a curve or the vehicle travels along a sloping terrain.[3] At given speed and/or slope conditions, a higher SSF value equates generally to a more stable, lower centre of gravity (CoG) less 'top-heavy' vehicle (and is also a function of wheel base and track width, depending on tip-over direction). Lateral SSF values across all road going light passenger vehicle types typically range from around 1.00 to 1.50. Most passenger cars have values in the 1.30 to 1.50 range.

[3] This report relates to four wheel vehicles and not two wheel vehicles such as motorcycles.

Higher-riding sports utility vehicles (SUVs), US pick-up trucks, and vans usually have values in the 1.00 to 1.30 range. Heavy Trucks are in the range of 0.35 to 0.5 depending on loading.

Using a tilt table, and measuring the angle at which the vehicle starts to tip, directly relates to a vehicle's static stability (Static Stability Factor or SSF) either when traveling around a curve or on a slope. Such stability parameters are particularly relevant to Quad bikes (and SSVs) as they are used (and promoted to be used) in a variety of terrains, including hilly and uneven ground and vegetation cover, which may expose them to a higher risk of rollover.

Despite the Quad bike Industry's widespread promotion of 'Active Riding' as a key part of Quad bike training and rollover and handling risk mitigation, the Authors have been unable to identify any study or publication (other than their own work), worldwide, whether by the Quad bike Industry, safety researchers or others, that comprehensively quantifies the benefits of Active Riding, whether it is in terms of increased static stability or crash risk reduction. While the Authors are fully in favour of appropriate rider/ driver training for Quad bikes and SSVs, this is only one component of a Vision Zero based Safe System Approach (safer vehicles, safer environment, safer people where deaths or serious injuries in the workplace that results in a permanent disability are not acceptable), not a substitute for vehicles to be designed to have static stability characteristics, which are appropriate to their intended usage.

An alternative view supported by the Quad bike Industry is that Quad bikes are a high mobility vehicle that enables access into a large variety of off-road terrains which is not practical using other four wheel vehicle types. The argument presented is that there is an inherent trade-off between mobility and stability, and that high mobility vehicles inherently have less static stability. The Authors accept this argument to a degree only – as there are examples of vehicles that have high mobility (including load carrying capacity) without compromising either static or dynamic stability. The Authors would argue such vehicles include the Tomcar and other SSV models, and that these vehicles can access steeper slopes and transverse rougher terrain without rolling over in circumstances where a Quad bike would likely rollover. A feature of Quad bikes is their relatively narrow track width which allows access to narrower tracks and openings than some of the vehicles with larger static stability. Clearly where such limited track width access requirements are not needed, vehicles with higher stability would be preferred, i.e. a 'Fit For Purpose' vehicle can be chosen.

There are no standards or compliance requirements in Australia for Quad bikes or SSVs. However, three main US Industry voluntary 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 the ANSI/OPEI B71.9-2012: American National Standard for Multipurpose Off-Highway Utility Vehicles. All relevant vehicles were checked for compliance with the respective standard. 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.

The Static Stability testing using the tilt table was carried out at Crashlab. The full Crashlab Test Report, methods used and all test results for each of the sixteen production vehicles tested are provided in Attachment 2. The Static Stability testing involved a comprehensive set of approximately 318 Static Stability tests for the 16 production vehicles, as set out in Table 3. Table 4 shows results for tests with the three different model OPDs.

The test results are presented in terms of the measured maximum Tilt Table angle at point of vehicle tip over for the test condition, and the Tilt Table Ratio (TTR), which is defined as the tangent (i.e. the rise divided by the run) of the maximum Tilt Table angle. The load combinations considered were: baseline (no rider or load); baseline + larger rider; baseline + larger rider + maximum front load; baseline + larger rider + rear maximum load; baseline + larger rider + front and rear maximum load. In all these tests the rider was a 'larger' rider (i.e. larger than the average rider) representing a 95th % adult male (PAM) (dummy mass was 101 kg, and with tie down straps a total of 103 kg test mass). A series of tests was carried out with OPDs for all these load combinations for the Lowest, Median and Highest roll static stability Quad bikes.

For the adult Quad bikes and the SSVs testing was conducted with the ('larger') 95th % adult male (PAM) Hybrid III Anthropomorphic Test Device (ATD) (i.e. crash test dummy) as a rider/driver. While a 95th PAM may not represent the typical or average rider size, it can be considered as an upper bound on likely intended use, and (as discussed subsequently) most farm usage (including any use of Active Riding on Quad bikes) could be considered to be bounded between the 'no operator' (i.e. baseline) configuration and the 95th PAM operator-only configuration. For the youth model Quad bike (the Can-am DS90X) a 5th percentile adult female dummy (5th PAF), which equates to a US 50th % 12 year old male child (at approximately 50 kg), was used.[4]

For the SSV tests only a driver dummy was used. For lateral rollover this is the worst case scenario for static stability (i.e. driver on lower side), and similarly for rear pitch rollover. For forward pitch rollover having two occupants may slightly reduce the forward pitch TTR, but as these values are already high, a small reduction would not be significant.

For lateral rollover Static Stability tests, Figure 6 shows the TTR results for all of the vehicles and full load configurations, including OPDs, and Table 5 summarises the range of the TTR test results for lateral rollover for the three vehicle categories and full loading combinations.

For forward pitch rollover Static Stability tests, Figure 7 shows the TTR results for forward pitch rollover for all of the vehicles and full load configurations, including OPDs and Table 7 summarises the range of the TTR test results for forward pitch rollover for the three vehicle categories and maximum loading combinations.

For rearward pitch rollover Static Stability tests, Figure 8 shows the TTR results for rearward pitch rollover for all of the vehicles and maximum load configurations, including OPDs and

[4] Fryar CD, Gu Q, Ogden CL. Anthropometric reference data for children and adults: United States, 2007–2010. National Center for Health Statistics. Vital Health Stat 11(252). 2012. http://www.cdc.gov/nchs/data/series/sr_11/sr11_252.pdf

Table 9 summarises the range of the TTR test results for rearward pitch for the three vehicle categories and full loading combinations.

In regard to compliance with the USA Industry voluntary Standards requirements for lateral rollover and forward and rearward pitch rollover static stability all the Quad bikes and SSVs tested would meet the respective static stability requirements from ANSI/SVIA 1-2010 Standard for Quad bikes (ATVs) and the ANSI-ROHVA 1-2011 Standard for SSVs. These results would indicate these Industry voluntary standard stability requirements are possibly set too low. The static stability requirement was assessed in the final report in terms of whether these Industry voluntary standards are set at the appropriate level when comparted to the dynamic tests, review of Coronial and hospitalisation data, and crashworthiness tests.

The Static Stability Overall Indices calculated are firstly based on the Tilt Table Ratio (TTR) indices measured for each of three Static Stability test directions, by summing and then averaging the TTR values for each full loading combination within those test directions. The Static Stability Overall Rating Index for each vehicle is then derived from the weighted index for each of the three test directions. To account for the different TTR magnitudes in each of the three test directions, in the spread sheet of the TTR results, each TTR value was normalised against a proposed benchmark TTR value for the respective direction. Thus the TTR point was adjusted by dividing by the proposed benchmark reference value of 1.0 (Tan 45°), 2.0 (Tan 63.4°) and 1.75 (Tan 60.2°), for the three directions, respectively.

To take into account the different relative incidence of lateral roll, forward pitch and rear pitch rollovers, a relative weighting of 2:1:1 was assigned. In the absence of comprehensive data of the incidence of roll directions in real world crashes, the weighting factors used reflects that lateral roll can occur in two directions (left and right) compared with one each for forward and rearward pitch. This weighting may change in the future if it is determined from analyses of real world Coronial data and hospitalisation data that the weighting may need to be re-evaluated according to injury risk exposure. The final Static Stability Overall Rating Index is thus determined by summing the normalised index for the three tilt-table test directions, but weighted in the ratio of 50% lateral rollover, 25% forward pitch rollover and 25% rear pitch rollover. The weighted index score has a maximum of 20.

Finally, the two Static Stability Indices developed were: Static Stability Overall Rating Index – System 1 with maximum loads, for the eight work Quad bikes and five SSVs is set out in Table 13 and Figure 9; and Static Stability Overall Rating Index – System 2 with rider with no loads, for the 8 work Quad bikes, 3 Sports/ Rec Quad bikes and the 5 SSVs is set out in Table 14 and Figure 10. The Sports/ Rec Quad bikes do not carry loads and hence only appear in the Static Stability Overall Rating Index – System 2.

Overall, the work Quad bikes with a large rider ATD and full load, for a vehicle intended to be used on slopes and ‘all-terrains’, have a lateral static stability (Tilt Table Ratio: TTR) varying from 0.41 to 0.55, which is lower than the SSVs. It is noteworthy that the highest stability work Quad bike is less stable than the least stable SSVs (i.e. using TTR).

For all the tested work Quad bikes, this suggests that such relatively low lateral static stability values are likely to be, in many cases, incompatible with traversing steeper slopes while fully loaded in the work environment and terrain in which such vehicles are being used, particularly on farms. This is warned against on Quad bike warning labels, training courses and owner's manuals.

These results are based on TTR and are further evaluated in Part 2 (Dynamic Handling tests).

Regarding forward pitch stability, work Quad bikes have a significantly higher TTR than lateral stability. In forward pitch, SSVs have higher TTRs than work Quad bikes, some by up to double. The lowest stability SSV is much more stable in forward pitch (i.e. higher TTR) than the highest stability work Quad bike, fully loaded or unloaded.

The rear pitch stability for work Quad bikes is similar to the forward pitch stability based on TTR. Rearward pitch stability is significantly higher than lateral stability. The SSVs have much lower rearward pitch stability than forward, up to 40% less. For the SSVs, rear pitch stability is about 20% higher than Quad bikes, with a large rider dummy and rear full load. However the rear full load for SSVs is much greater than for Quad bikes.

For the OPDs, the Quadbar (8.6kg) has a minor effect on the static stability of the work Quad bikes. The Lifeguard (14.8kg) similarly has a small effect only on lateral and forward pitch static stability, but with a greater effect on rear static stability (approx. 10% reduction). The Quickfix unit being heavier (30kg) and higher, has a more pronounced effect compared to the other OPDs on static stability, reducing the TTR, for example by about 11% laterally and 14% in forward pitch. Attaching OPDs such as the Quickfix unit would lower the TTR even further (on top of relatively low static stability values for Quad bikes in general) and thus additionally reduce the vehicle's rollover resistance. The Quickfix unit also restricts a rider from standing upright on the vehicle limiting any Active Riding. Thus the Quickfix unit not recommended for fitment as an OPD to any Quad bike.

Based on these results the SSVs provide higher stability based on TTR which would suggest a higher rollover resistance. These results were further evaluated taking into account the Dynamic Handling tests.

These Static Stability Indices indicate that if the Quad bikes tested were to be used to carry various loads such as hay bales, animals, liquids in tanks for spraying purposes or any other loads, this would present a lower resistance to roll-over for the rider compared to using any of the SSVs tested, under similar operating circumstances. This clearly indicates that in terms of 'Fit for Purpose' for a workplace farming environment, the SSVs present a higher rollover resistance than Quad bikes.

2 THE QUAD BIKE PERFORMANCE TEST PROJECT

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

The Heads of Workplace Safety Authorities (HWSA) has identified Quad bike safety to be a major issue on farms in Australia and New Zealand. They state that "*In Australia, more than 64 per cent of quad bike deaths occur on farms and in the last 10 years there have been 130 quad bike fatalities across the country. In New Zealand, five people (on average) are killed on farms and over 845 injuries reported each year*."

HWSA and the Quad bike Industry supported Working Group developed a strategy aimed at reducing fatalities and injuries from Quad bike use on farms in a work setting. Part 7 of that Strategy document was 'Design'. This related to the aim to 'critically consider engineering and design features' for improved vehicle static stability, and improved crashworthiness including rollover protective devices (including retrofit of safety accessories).

Justification to consider improving vehicle static stability and rollover crashworthiness was initially based on recent data presented by Lower and Fragar (2012) on the 127 Quad bike deaths in Australia between 2001 and 2010. They found *"65% of fatalities occurred on-farm, with 45% of incidents being work-related and 46% involving rollovers of the quad bike."* They further found: *"Analysis of the nature of the crash event highlights the leading mechanisms of injury as: collision with stationary object (34), rollover with no load or attachments (33), collision with other vehicle (10) and rollover with spray tank (9). Rollover of the quad bike [was] attributed to 46% of all deaths where the mechanism of injury was known. Additionally, where the work status and mechanism were known, rollovers accounted for 58% of deaths."*

In a more recent study Lower (2013) further identified in the 12 year period 2001 to 2012:

- over 170 fatal cases, representing approximately 14 fatalities per year;
- approximately 60% of all Quad bike related deaths involved rollover;
- over 89% of rollover deaths occurred on farms.

Further detailed analysis reported elsewhere in QBPP reports by the Authors (Grzebieta, Rechnitzer, et al. 2015a; Grzebieta, Rechnitzer, et al., 2014b; McIntosh and Patton, 2014a) has also identified crush and asphyxiation as being one of the injury mechanisms occurring in Quad bikes fatal rollover crashes that is of concern to workplace Work Health and Safety regulators and farmers.

In response to the incidence of fatal and serious injury rollovers involving Quad bikes, and the Quad bike Industry response that provision of rollover protection systems on these vehicles are hazardous[5], it has been proposed by some authorities and other safety advocates, that as a minimum Operator Protection Devices (OPDs) such as the devices shown in Table 2, be installed on all workplace Quad bikes. This proposal is based mainly on the observation that a Rollover Protection System (ROPS) fitted to old and new tractors has resulted in a marked reduction of tractor fatalities (Franklin et al., 2005) and hence, by analogy, might be effective in reducing Quad bike rollover harm.

While in principle it appears that such systems may have a protective benefit in some rollovers, it is also clear that fitment of OPDs will not prevent rollover from occurring in the first instance and OPDs may not be effective in all rollover situations (Grzebieta and Achilles, 2007), as active separation or ejection still occurs and impact or crush by stiff areas on the Quad bike may still result. Other than the reports by the Authors, Australian research on the effectiveness of OPDs based on fatality and hospital data has yet to be done. Some USA research has been carried out and published based predominantly on computer simulations and tests, and similarly no US cohort studies have been carried out to assess the effectiveness of OPDs in the field.

Thus, there has been little agreement on the way forward in improving Quad bike safety in regard to rollover[6]. The Quad bike Industry[1] position remains focused on rider training, administrative controls and personal protection equipment (PPE) such as helmets.

The Authors of this report support administrative controls, albeit as one component of a larger holistic Safe System Approach which should include increasing rollover resistance and enhancing rollover crashworthiness design, while still maintaining the operational capabilities of the vehicles. Hence, increasing rollover resistance and enhancing rollover crashworthiness design should be one of the components considered in such a Safe System Approach.

In contrast, users of Quad bikes, farm Quad bike Industry groups, safety regulators, and safety researchers, see from the history of safety advances in road vehicle transport that design countermeasures are possible, and that fitment of OPDs to Quad bikes is seen as a means of harm minimisation, but that the Quad bike Industry continues to negate promotion of or indeed adequately research any solutions concerning fitment of OPDs. The Quad bike Industry's resistance to fitment of OPDs (in their view) is that there is no scientifically valid research indicating that fitment of OPDs would be effective, not harmful and not compromising the capabilities of the vehicle.

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[5] http://safetyatworkblog.com/2011/05/19/quad-bike-manufacturers-walk-out-of-safety-working-group/

[6] FCAI, (2012). ATV Industry opposes rollover devices on safety grounds. http://www.fcai.com.au/news/news/all/all/311/atv-industry-opposes-rollover-devices-on-safety-grounds.

Hence, there exists a decades-long impasse on advancing Quad bike rollover crashworthiness safety and the need for a new approach, as a way ahead to reduce Quad bike trauma (Rechnitzer et al., 2013).

Whilst the Authors agree with the Quad bike Industry that further in-depth injury data relating to the characteristics of Quad bike and SSV rollover crashes to vehicle stability, handling and crashworthiness design would be of benefit, the Authors disagree that vehicle design safety advances cannot proceed until such data is fully obtained and analysed. This argument should not be used to hinder safety design advancement for Quad bikes and SSVs, i.e. we should not let perfection be the enemy of the good. The Authors consider that until such data can be obtained, the principles established over the past 50 years in mobility safety can be usefully and appropriately applied to Quad bike and SSV safety design.

What is clear is that rollover is a major contributor to fatal and serious injury outcomes involving Quad bikes, and therefore measures aimed at reducing both the incidence and severity of rollover are obvious injury prevention countermeasures that should be strongly advanced. The Authors do not agree that Quad bikes and SSVs are exempt from such fundamental safety principles which apply to all mobile vehicles that transport people (e.g., cars, trucks, trains, trams, buses, etc.). A pro-active approach should be taken rather than waiting another decade until such data may become available with many additional casualties occurring as a consequence of such delays.

On this basis, this Project is aimed at addressing Part 7 of the Strategy (Design) and the current technical challenges in improving vehicle-centred safety of Quad bikes and SSVs, in the farm environment. This will be done through the development of a Quad bike and SSV star safety rating system (ATVAP: Australian Terrain Vehicle Assessment Program).

The use of a Star Rating system to inform consumers has been widely used and accepted by the general public, stakeholders and much of Industry. Examples include star ratings for white goods product energy efficiency, water efficiency (dishwashers, washing machines, etc.), consumer financial products, and for vehicles the very successful Australasian New Car Assessment Program (ANCAP), e.g. stars on cars for vehicle safety. Indeed, ANCAP has been a catalyst for and helped promote large technological safety advances that have delivered major safety benefits in terms of reduced community trauma in the case of road vehicles.

It is hoped that ATVAP will provide similar benefits for consumers. The objective is to introduce a robust, test based rating system, in order to provide workplace and consumer based incentives for informed, safer and appropriate vehicle purchase (highlighting 'Fit For Purpose' criteria), and at the same time generate corresponding incentives and competition amongst the Quad bike and Side by Side Vehicle (SSV) Industry for improved designs and models. The premise is that Quad bikes with a higher resistance to rollover and improved crashworthiness will result in reduced rollover related fatalities and serious injuries, i.e. that those vehicles receiving high stability and crashworthiness index values, in fact have been found to have lower fatality rates.

Following completion of the project final report and implementation, it is hoped the Star Rating system will be evaluated progressively over the years based on real world field injury and fatality data similar to how ANCAP was assessed after its implementation in 1993 (Newstead and Cameron, 1997).

The bulk of the Project has been funded by the WorkCover Authority of New South Wales (Australia) with support by the State Government of New South Wales (NSW) with some additional funding provided by the ACCC to include the three selected recreational Quad bikes into the test matrix.

The Quad Bike Performance Project (QBPP) commenced in September 2012 and the last series of testing (Rollover Crashworthiness) was completed by around June 2014.

The project consists of three parts: Part 1 focusses on Static Stability; Part 2 focusses on Dynamic Handling; Part 3 focusses on Rollover Crashworthiness. This report presents the results of Part 1: Static Stability Test Results and Rating of 17 Quad Bike and Side by Side Vehicles (SSVs). There is a fourth report (Report 4) which is titled Final Project Summary Report: Quad Bike Performance Project Test Results, Conclusions and Recommendations. There is also a Supplemental Report that presents a summary of the 'Examination and Analysis of Quad Bike and Side By Side Vehicle (SSV) Fatalities and Injuries' carried out by McIntosh and Patton (2014a) and Mitchell (2014) and some further analysis by the co-Authors Grzebieta, Rechnitzer and Simmons.

3 STATIC STABILITY TEST PROGRAM FOR QUAD BIKES AND SSVs

3.1 Introduction

The Project aims to significantly advance the safety of Quad bikes (also commonly referred to as ATVs in the USA and sometimes in Australia), and appropriate vehicle selection for workplace and farm use, based on a comprehensive test program and development of a Star Rating system. The proposed Star Rating system will be named Australian Terrain Vehicle Assessment Program (ATVAP).

The objective is to introduce a robust, test based rating system, correlated to fatality and serious injury outcomes for the tested vehicles, in order to provide consumer information for informed, safer and appropriate vehicle purchase (highlighting 'Fit For Purpose' criteria), with corresponding competition amongst the Quad bike Industry for improved designs and models.

The particular focus of this report is static stability (rollover resistance) characteristics of the Quad bike and SSV vehicles, as rollover (lateral roll, rear pitch roll and forward pitch roll) has been identified from the fatality data as being a major incident and injury mechanism in the workplace.

The relevance of vehicle handling (and stability) in regard to the other crash modes (frontal impact, loss of control etc.) will be further considered in Part Two of this project involving the Dynamic Handling tests and indices. Part 3 focusses on the rollover crashworthiness of the vehicle and harm minimisation characteristics which relate back to actual real world rollover crash fatalities.

The project aims are:

1. Establishment of Static Stability, Dynamic Handling and Rollover Crashworthiness ratings for the selected Quad bike and SSV models;
2. Development of a rating system Australian Terrain Vehicle Assessment Program (ATVAP) comprising rollover Static Stability, Dynamic Handling and Rollover Crashworthiness correlated with real world incident outcomes.

The test program has several major components:

1. The selection and purchase of 16 new representative production Quad bikes and Side-by-Side vehicles as shown in Table 1, and set out in the Crashlab test report Attachment 2. Details of how the vehicles were selected explained in Section 3.1.1.
2. Biomechanics injury analysis based on Quad bike and Side by Side Vehicle (SSV) injury data obtained from the United States of America (USA) Consumer Product Safety Commission (CPSC) and the Australian National Coronial Information System (NCIS). Further detailed analysis and identification of injury mechanisms related to Quad bike and SSV fatal crashes, particularly rollover, and especially related to crush and asphyxiation were carried out. This in turn formed the basis of the development

of related crashworthiness test methods. This task was not completed until December 2013, mainly as a result of delays in obtaining detailed Coronial case files;

3. Series of Static Stability tests for lateral rollover and forward and rearward pitch rollover, based on tilt table tests with and without a rider (Hybrid III Anthropomorphic Crash Test Dummy (ATD)), and with combinations of maximum cargo loads on the front and rear. Effects of a selected sample of operator protection type devices (OPDs) on static stability were also tested [This report: see Attachment 2];

4. Establishment of Static Stability Indices for the selected Quad bike and SSV models (this report);

5. Series of Dynamic Handling tests have started. Tests include the ISO 4138:2012 Passenger Cars - Steady State Circular Driving and the ISO 7401:2011 Road Vehicles - Lateral transient response – open loop test methods, both modified for a Quad bike and a SSV. An obstacle perturbation test (simulating riding one side over a rock like object) will also be included. Components of these tests will complement the static stability evaluation. The results form part of the ATVAP rating for Dynamic Handling and incorporation into the overall vehicle Static Stability, Dynamic Handling and Rollover Crashworthiness Star Rating. Improvements in Quad bike and SSV handling has been suggested by authors such as Roberts (2009) and others as being a practical means to reduce crash and rollover risk. Part 2 of the QBPP Project was completed in January 2014

6. Series of crashworthiness tests related to lateral rollover and front and rear pitch rollover, to determine serious injury risk, with and without OPDs. The tests will be based on the outcomes from the injury analysis of CPSC and NCIS data and identification of rollover related injury mechanisms. The crashworthiness test series (Part 3) were completed in June 2014;

7. Development of a Static Stability, Dynamic Handling and Rollover Crashworthiness Star Rating system, Australian Terrain Vehicle Assessment Program (ATVAP), that combines the assessments of all three Parts, namely rollover Static Stability, Dynamic Handling and Rollover Crashworthiness components, into a 5 Star Rating system.

The testing program was undertaken at the NSW Roads and Maritime Services Crashlab test facility in Sydney, NSW, Australia.

The sixteen production vehicles selected for testing included eight Quad bikes which are examples 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 [see Table 1]. The three sports/recreational Quad bikes were added to the project and funded by the Australian Competition and Consumer Commission (ACCC). Quad bike vehicles, often called All-Terrain Vehicles (ATVs) particularly in the USA, are four-wheeled vehicles designed so that the rider straddles the vehicle similar to a two wheel motor-cycle. Side by Side Vehicles (SSVs) are design so that a rider is seated in the vehicle similar to how a driver sits in a small car. SSVs are also designed so a passenger can sit alongside the driver (hence the name Side by Side).

Before presenting material on the Static Stability Indices for the Quad bikes and SSVs, some discussion is necessary concerning the use of the terminology 'All-Terrain Vehicles' (ATVs). In Australia, the terms adopted for vehicles used on farms over rougher terrains are Quad bikes or Side-by-Side Vehicles depending on their seating configuration. Quad bikes are distinguished from SSVs by their design, namely the Quad bike's straddle seating, handlebar steering and low pressure tyres compared to the SSVs upright seating, steering wheel and higher tyre pressure. SSVs are distinguished from various larger four wheel off-road vehicles by their limited width, limited gross vehicle weight rating and limited engine capacity as per the ANSI/SVIA and ANSI/ROHVA standards. However, the term All-Terrain Vehicle or ATV is sometimes used in Australia and it is commonly used (and under USA law) to represent a Quad bike in the USA. One potential confusing factor is the continuing use of the terms 'quad', 'quad bike', 'ATV' and 'All-Terrain Vehicle' by the media, by accident investigators, by Coroners, and by others, which has often been used to refer to both Quad bikes and Side-by-Side Vehicles. Both an Australian Coroner (Olle, 2009) and the USA CPSC (Elder and Leyland, 2006) have indicated that the term 'All-Terrain Vehicles' is misleading and may result in false assumptions as to the terrain that such vehicles can safely traverse, hence in Australia the terms Quad bike and Side-by-Side Vehicle are preferred and will be used throughout this report.

In Australia, it is estimated[7] that there were approximately 270,000 Quad bikes and SSVs in use in 2010 (Australian ATV Distributors, 2010). This compares to an estimated 80,000 Quad bikes and SSVs in use in New Zealand agriculture in 2010 (Carman et al., 2010) and an estimated 10 million Quad bikes and SSVs in use by 16 million individuals in 2008 in the United States (US) (Helmkamp et al., 2011).

SSVs are increasingly being used on farms and workplaces in place of Quad bikes, and are part of the 'Fit For Purpose' vehicle selection being promoted in a number of cases by the Quad bike industry groups.

It was for this reason, and the recognition that improved Quad bike rollover safety may well require far more than the simple fitting of OPDs (Operator Protection Devices), that this project was expanded to include SSVs and not only Quad bikes. The test results clearly demonstrate that the inclusion of SSVs has proven to be most valuable and significant, providing a much needed context and relative Static Stability Overall Rating Index to compare Quad bike static stability values against. Moreover, it was clear from the outset that OPDs do not prevent rollovers and in some cases may adversely affect rollover resistance. However, effectiveness of OPDs will be assessed in Part 3 (focussing on Rollover Crashworthiness).

[7] From Mitchell (2014).

3.1.1 The seventeen test vehicles

The 17 vehicles tested are set out in Table 1 below. Test vehicle specification details for the 16 production vehicles are provided in Attachment 2 in the Crashlab Quasi Static Tilt Testing report, Appendix D.

In regard to Quad bike selection, the intent was to obtain examples of new Quad bikes and SSVs typically sold in Australia and in use, subject to the limitations of the project budget. The following selection criteria were considered:

1. Highest Sales by manufacturer (Yamaha, Honda, Suzuki, Polaris, Kawasaki 2008-2011)
2. Common or popular models for these manufactures, by sales data and as suggested by major Quad bike distributors in NSW and Victoria;
3. Representation by imported higher sales Taiwanese (Kymco) and Chinese models (CFMoto)
4. Australian Quad bike Fatality data by Quad bike manufacturer (Yamaha, Honda, Suzuki; Polaris, Kawasaki in that order);
5. Quad bike engine size by fatality (350cc and 500cc identified; although data very limited);

For the three sports/ recreational models, these were selected by the Australian Consumer and Competition Commission (ACCC) in consultation with Quad bike distributors. One of the models included a youth model.

In regard to the SSV selection, the criteria were based on obtaining vehicles from a retail price ranging from lower cost to higher cost (e.g. Kubota to Honda MUV700), and different model designs which are in more common use (Yamaha Rhino, John Deere; Honda and Kubota). The fifth SSV selected was from an Australian manufacturer in that the model was just coming onto the market in Australia for farm use, but had a pedigree of being a high mobility vehicle based on an Israeli army ‘all-terrain’ model. It was included in the test series as providing a potential benchmark for good stability, handling and crashworthiness.

Major dealerships were also consulted in country Victoria (Warragul) and country farm centres in NSW (Moree: Thomas Lee Motorcycles - a large Quad bike dealership) to finalise the selected list of Quad bikes and SSVs.

Obviously the 16 production vehicles selected and tested are the beginning of such evaluations, and as with other products that are star rated such as white goods, cars, child restraints, etc., hopefully, more vehicles will be tested in the coming years, if and when the ATVAP rating program expands and enhances into the future.

3.1.2 Operator Protection Devices (OPDs)

To measure the effects on Quad bike static stability when OPDs are attached, tests were carried out with three different model OPDs (see Table 2) fitted to the 3 ‘work’ Quad bikes. The OPDs were not able to be fitted to the Sports/ Rec Quad bikes, as none of the units had

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

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

Table 1: The 17 Test Vehicles

Quadbar	Lifeguard	Quick-fix OPD
QB Industries	Ag TECH industries	Quick-fix
8.5kg	14.8kg	30.0kg
		

Table 2: The three OPD units used in the tilt-table tests with the 'work' Quad bikes

any vehicle manufacturer 'approved' mounting points nor was there any practical location for mounting these units. Manufacturers state that they do not support the fitment of OPDs to Quad bikes[2]. As an integral part of the vehicle's design the SSVs were fitted with ROPS and restraints at the point of manufacture.

3.2 Rollover Quad Bikes is the Predominate Fatal Injury Mechanism

In Australia, Quad bike rollover-involved crashes represent the major mechanism in fatal and serious injuries for Quad bike users, particularly in the farming sector. Similarly in the USA, Quad bike rollover is also a major mechanism, but with more recreational and on-road incidents than off-road farm related incidents.

As mentioned earlier, in his most recent study of Australian fatalities involving Quad bikes in the 12 year period 2001 to 2012, Lower (2013) identified:

- over 170 fatal cases[8], representing approximately 14 fatalities per year;
- approximately 60% of all Quad bike related deaths involved rollover though in some cases it is not clear whether the rollovers occurred before or after the injurious event, and before or after rider separation from the vehicle. In some cases the fact the vehicle has rolled over may not necessarily be causal to the resulting injury;
- over 89% of rollover deaths occurred on farms.

[8] The detailed Coronial case files collected by McIntosh and Patton (2014a) were further reviewed to identify the nature of the fatalities regarding Quad bike and SSV fatalities and are reported elsewhere.

Such findings are consistent with earlier findings of the Authors' 2003 study "All Terrain Vehicle Injuries and Deaths" (Rechnitzer et al., 2003) which also identified ". ..*rollovers are the major cause of fatalities*" in Quad bike fatal incidents. Further detailed analysis reported elsewhere in QBPP reports by the Authors (Grzebieta, Rechnitzer, et al. 2014a; Grzebieta, Rechnitzer, et al., 2014b; McIntosh and Patton, 2014a) has also identified crush and asphyxiation as being one of the injury mechanisms occurring in Quad bikes fatal rollover crashes that is of concern to workplace Work Health and Safety regulators and farmers.

In terms of location and activity, as mentioned earlier, Lower, Herde and Fragar's (2012) study of 127 Quad bike related deaths for the period 2001 to 2010 identified[9] that approximately 65% of Quad bike fatalities occurred on farms and of these some 65% of fatal incidents occurred when the machine was being used for work. This is in contrast to the deaths occurring off-farm, where 9% of deaths were associated with a work activity. The Authors' findings (Grzebieta, Rechnitzer, et al. 2014a; Grzebieta, Rechnitzer, et al., 2014b; McIntosh and Patton, 2014a) are consistent with Lower, Herde and Fragar's (2012) findings.

The Lower, Herde and Fragar (2012) study also noted that "*Presence of a load appears to be a factor in quad bike rollover deaths, with one third of rollovers involving a load or attachment on the machine such as the carrying of passengers, fitment of a spray tank or unit and the towing of trailers.*"

A study of Quad bike fatalities in the USA using CPSC data by McIntosh and Patton (2014b) for the 11 year period 2000 to 2010, identified some 6552 cases involving 4 wheel Quad bikes, of which 2774 fatal cases involved single riders over 16 years of age. Of these some 92% were male riders. Rollover/overturn was the single main incident type (over 54%), followed by a collision with stationary object. Overturn direction was not well identified in 90% of cases. Moreover, McIntosh and Patton (2014a) also identified that rollover occurred in 71% of the Australian Coronial cases they analysed in detail.

In regard to appropriate test methods for static stability, the Quad bike Industry Representatives on the Project carried out an independent analysis of Quad bike and SSV incident data from the UK, USA and Australia, confirming the relevance of Tilt Table testing of these vehicles, as follows.[10] The following extracts are in regard to the static stability testing only.

> ***"a. ATVs[11] - i. Stability Testing.*** *In regard to ATV stability testing, the accident data in Table 1 would support the concept of static stability tilt table measurement (upslope,*

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[9] Of the 127 fatal cases, not all incidents had data available to enable categorisation regarding location, activity, workplace, cause of death, nature of incident, etc.

[10] Communication from Dr. John Zellner to the Project Reference Group "*Suggested Outline For Accident-Data-Driven Existing-Technology-Based Test Methods For Small Off-Road Vehicles*," 24 May 2013. Dr. Zellner has published extensively on ATV handling and safety issues. Dr. Zellner with Mr. Cameron Cuthill and Mr. James Hurnall are FCAI representatives on the Project Reference Group.

[11] Quad bikes.

downslope, cross-slope) for '2-wheel lift', adapting to ATVs the test methods in ANSI/ROHVA 1-2011. A potential factor is how to account for 'rider active' body positioning and rider size and weight effects, as previously discussed."

"SBSs[12] - i. Stability Testing*. Table 1 indicates that for SBSs, 'flat turns' are the most frequent overturn accident condition (44%), followed by 'slope' (26%) and 'slope combined with other control input and/or terrain input' (17%). Discrete obstacles and/or other types of terrain and/or control inputs are each observed to account for a relatively small percentage of SBS overturns.*

In regard to SBS stability testing, the accident data in Table 1 would support the concepts of:

- *Static stability tilt table measurement (upslope, downslope, cross-slope) using the ANSI/ROHVA 1-2011 test procedures for '2-wheel lift'; and*
- *Dynamic (circle) testing to measure the lateral acceleration for '2-wheel lift' using the ANSI/ROHVA 1-2011 test procedures."*

3.3 Relevance of Vehicle Static Stability Measures to Rollover Risk for Quad Bikes and SSVs

Fundamental engineering and scientific principles, as well as universal experiential knowledge, recognises that static stability is an essential criterion for systems whether stationary or mobile.

Basically, no one wants our buildings, bridges, household furniture, structures or indeed us to tip over, unintentionally. The same applies to mobile structures - and vehicles of all types - which we do not want to rollover. The consequences of vehicle tip over or rollover are well known in terms of fatal and serious injury risk (see for example Richardson, Grzebieta & Rechnitzer, 2003).

The defining characteristics for static stability are all very similar, and of course obey the laws of physics and the actions of bodies under the force of gravity. Essentially for a stationary body and in many cases a moving body, to not tip over, it must have a 'footprint' large enough to overcome any lateral forces 'acting' on it.

For a vehicle, that means that the overturning forces acting at the height of the centre of gravity (CoG) such as downward gravitational force on a slope, or centripetal acceleration for a vehicle in motion around a curve, can be resisted by the vehicle's weight acting vertically through its CoG about the point of overturning (i.e. the base width, or wheel track/ wheel base).

For vehicles, two key parameters affect lateral tip-over or rollover static stability: track width (distance to wheel centres) and centre of gravity height, specifically the ratio of CoG

[12] SBS is an acronym for Side By Side vehicle, called in this report SSV.

height to half the track width. As an axiomatic generalisation applicable to dual track vehicles, the wider the track width and the lower the CoG height, the more stable (against rollover) a vehicle is.

This is exemplified for example, by racing cars having high rollover static stability due to a wide track and low CoG. On the other hand, heavy loaded trucks generally have relatively low roll static stability, having a high CoG relative to their track width.[13]

The static stability performance envelope of a vehicle is largely dictated and set by these parameters of CoG height and track width for lateral rollover, and similarly for forward or rearward pitch by the vehicle's wheelbase and CoG position (CoG height and longitudinally position relative to the vehicle's wheels). The CoG height is also affected (usually increased and thus static stability decreased) by any loads being carried by the vehicle, including rider/ driver and occupants.

While other variables such as suspension design, and handling[14] can affect the lateral acceleration which may result in a rollover (i.e. increase or decrease the lateral acceleration at 2-wheel lift), the principal stability characteristics for a vehicle are constrained[15] within the vehicle's fundamental geometric properties of CoG height (and how this varies with any load), wheel base and track width.

3.3.1 Static Stability Factor (SSF), Tilt Table Ratio (TTR), and lateral acceleration at tip over

In the USA, in reconsidering rollover metrics, the National Highway Traffic Safety Administration (NHTSA) made the following comment on why Static Stability Factor (SSF) was selected as an appropriate metric for light passenger vehicle rollover resistance (NHTSA[16]) as an addition to the 2001 US NCAP.

> "*The agency favors static stability factor because it is applicable to both tripped and untripped rollover. The causal basis for its good correlation to crash outcomes is clear. It is relatively simple for consumers to understand and can be measured inexpensively with good accuracy and repeatability. Also, changes in vehicles to improve static stability factor are very unlikely to cause unintended consequences*."

The SSF is a common metric used to define vehicle rollover resistance, and is defined as one half the average front and rear track width divided by the total vehicle CoG height as follows

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[13] For example in New Zealand for heavy vehicles the minimum SRT specified is 0.35 http://www.nzta.govt.nz/resources/factsheets/13e/static-roll-thresholds.html

[14] The Dynamic Handling tests for this Project are analysed in Part 2 of this Project.

[15] It is noted that with modern vehicles electronic stability control systems (ESC) have been installed to prevent loss of control leading to rollover crashes. Such ESC systems may similarly become relevant for Quad bikes and SSVs to help reduce the incidence of rollover.

[16] See http://www.nhtsa.gov/cars/rules/rulings/rollover/Chapt05.html

$$\boldsymbol{SSF = \frac{T}{2H}}$$ **Equation 1**

where T is the ‘vehicle track width’; H is the ‘CoG height from ground surface’.

While SSF is called the Static Stability Factor, this should not be inferred that it only relates to a stationary (static) vehicle condition, i.e. when the vehicle is not in motion. The SSF is fundamentally related to and derived from the physics relating to vehicle stability and is relevant to a vehicle both on a slope (stationary or moving) and in turning manoeuvres (circular motion). While it is recognised that other factors such as suspension characteristics, vehicle tracking angle, etc., can affect the vehicle’s stability on a slope or when yawing, SSF is a first order dominant stability characteristic that governs the fundamental stability of the vehicle (Richardson, Grzebieta & Rechnitzer, 2003).

In the following analyses and equations:

SSF = Static Stability Factor;
TTR = Tilt Table Ratio;
V= vehicle velocity (m/s);
A= lateral acceleration (m/s^2)*;*
g = acceleration due to gravity = 9.81 m/s^2*;*
F= force (N)
M = vehicle mass (kg)
W= vehicle weight (= Mg) (N)
r= curve radius (m);
H= CoG height above ground (m);
T= track width; and $\frac{T}{2}$ *= half the track width (m).*

From the physics of circular motion (see Perrone, 1998), the centripetal acceleration on a vehicle is given by the standard equation:

$$\mathbf{A_C = \frac{V^2}{r}}$$ **Equation 2**

and thus the lateral or overturning centripetal force can be determined from:

$$\boldsymbol{F_C = \frac{M\mathbf{V}^2}{\mathbf{r}}}$$ **Equation 3**

At the point of overturning (Figure 1), the moment of the lateral centripetal force (F_c) and the stabilising force (F_w=Mg) from the vertical weight of the vehicle (M) just balances such that, taking moments about point OP gives Equation 4: [17]

$$\boldsymbol{F_C H = \frac{F_W \mathbf{T}}{2}}$$ **Equation 4**

[17] This is slightly simplified and is for the case of equal front and rear track. Second order effects not taken into account in these equations include neglecting vehicle roll displacement and changes in the effective tyre contact point locations due to suspension and tyre defections, etc.

Substituting for the forces in Equation 4, gives Equation 5:

$$\frac{MV^2H}{r} = \frac{Mg\text{T}}{2} \qquad \textbf{Equation 5}$$

Simplifying Equation 5 gives Equation 6, at point of tip over:

$$\frac{V^2}{gr} = \frac{T}{2H} = \textit{SSF} = \textit{Static Stability Factor} \qquad \textbf{Equation 6}$$

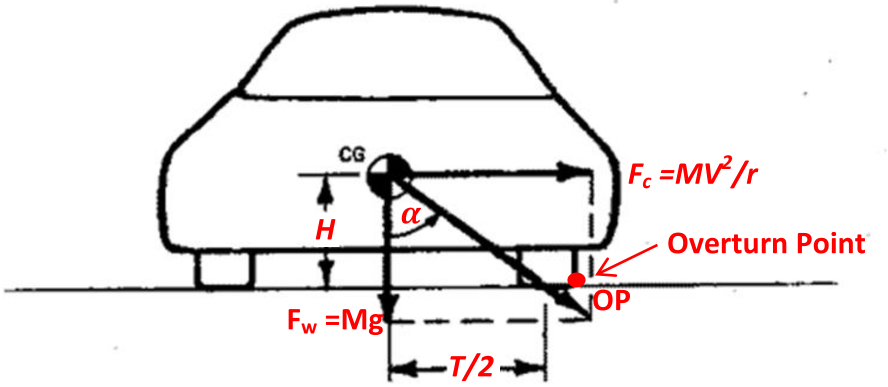

Figure 1: Forces acting on a vehicle in circular motion, and components of the SSF at critical lateral acceleration (point of rollover). Based on Figure 1 in 'Why Choose SSF'. From NHTSA: http://www.nhtsa.gov/cars/rules/rulings/rollover/Chapt05.html. (symbols in red added by the Authors).

In Equation 6, the right side of the Equation is the Static Stability Factor (SSF) = $\frac{T}{2H}$.

As shown simply by Perrone (1998) from fundamental physics, the vehicle will turnover when the speed (*V*) and curve radius (*r*) parameters in Equation 7 exceed the Static Stability Factor.[18]

$$\frac{V^2}{gr} > \frac{T}{2H} = \textit{SSF} = \textit{Static Stability Factor} \qquad \textbf{Equation 7}$$

From Equation 7, notably, at tip over the value $\frac{V^2}{gr}$ is the centripetal lateral acceleration in 'g' ($g = 9.81\ m/sec^2$), and equals the SSF.[19] That is, the Static Stability Factor approximates the lateral acceleration at tip over.

18 Some vehicles will slide out and not turnover if the vehicle's SSF is high enough, and depending on the surface frictional resistance or other mechanical resistance to vehicle lateral movement (e.g. a kerb or furrow tripped rollover).

19 It is worth noting that in New Zealand Static Roll Threshold (SRT) = (T/2H) – Ø where Ø is the roll angle in radians due to the compliances in the tyres, suspensions and other parts of the vehicle (see pp. 6-7 of SRT Calculator User Guide, TERNZ, 2006)

3.3.2 Mengert chart and SSF

The lower the SSF number, the lower the resistance of the vehicle to rollover. A higher SSF value equates generally to a more statically stable, lower centre of gravity (CoG) less 'top-heavy' vehicle (and is also a function of wheel base and track width, depending on tip-over direction). Lateral SSF values across all road going light vehicle types typically range from around 1.00 to 1.50. Most passenger cars have values in the 1.30 to 1.50 range. Higher-riding SUVs, US pick-up trucks, and vans usually have values in the 1.00 to 1.30 range. Heavy Trucks are in the range of 0.35 to 0.5 if heavily loaded.

For passenger vehicles, there is the well known NHTSA (Mengert, 1998) developed relationship between vehicle rollover crash involvement and a vehicle's Static Stability Factor (SSF), as shown in Figure 2, and shows the increased rollover risk with reducing SSF for passenger cars. Almost 40,000 rollover crashes were studied, which included almost 5,000 rollovers and 40 measured makes/models of vehicle. There was a strong correlation of rollover probability with Static Stability Factor.

Likewise for heavy vehicles, a similar chart to Mengert et al. (Figure 3) has been used by both the New Zealand Transport Agency[20] and the Australian National Road Transport Commission (NTC) who have published various documents and requirements regarding Performance Based Standards (PBS) for heavy vehicles, including a rollover stability requirement in terms of Static Rollover Threshold (SRT). This shows the strong relationship between reduced rollover resistance and increased rollover rate for heavy vehicles. For example, for an SRT of 0.6 the relative crash rate of approximately 1.0 compares with four times that value for an SRT less than 0.3. Both charts (Figures 2 & 3) are not surprising and are of course consistent with the fundamental laws of physics as would be expected and as described above.

Implications of Lower SSF for Quad bikes and SSVs

The important observation from both Figures 2 and 3 is that the Static Stability Factor (SSF) for any particular vehicle is relevant to rollover crash risk for not only lighter passenger cars but also through to heavy trucks. It is evident that such stability measures should similarly be applicable[21] to Quad bikes and SSVs which have stability factors in-between these two very different vehicle types (see Section 4 results of this report). Figures 2 and 3 show that vehicles with a lower rollover resistance are at a higher risk of rollover crash involvement. Thus with a higher exposure to rollover crashes, it would be expected that drivers/riders would be exposed to an increased risk of rollover related injury. As more detailed Australian injury data is collected and assessed for Quad bikes and SSVs this relationship will be able to be verified or otherwise.

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20 (DIER, 2006) http://www.nzta.govt.nz/resources/factsheets/13e/static-roll-thresholds.html

21 The relevance of SSF to SSVs is also discussed in detail in the 2009 CPSC Briefing Package in regards to Advance Notice of Proposed Rulemaking (ANPR) for Recreational Off-Highway Vehicles (ROVs) Oct, 2009.

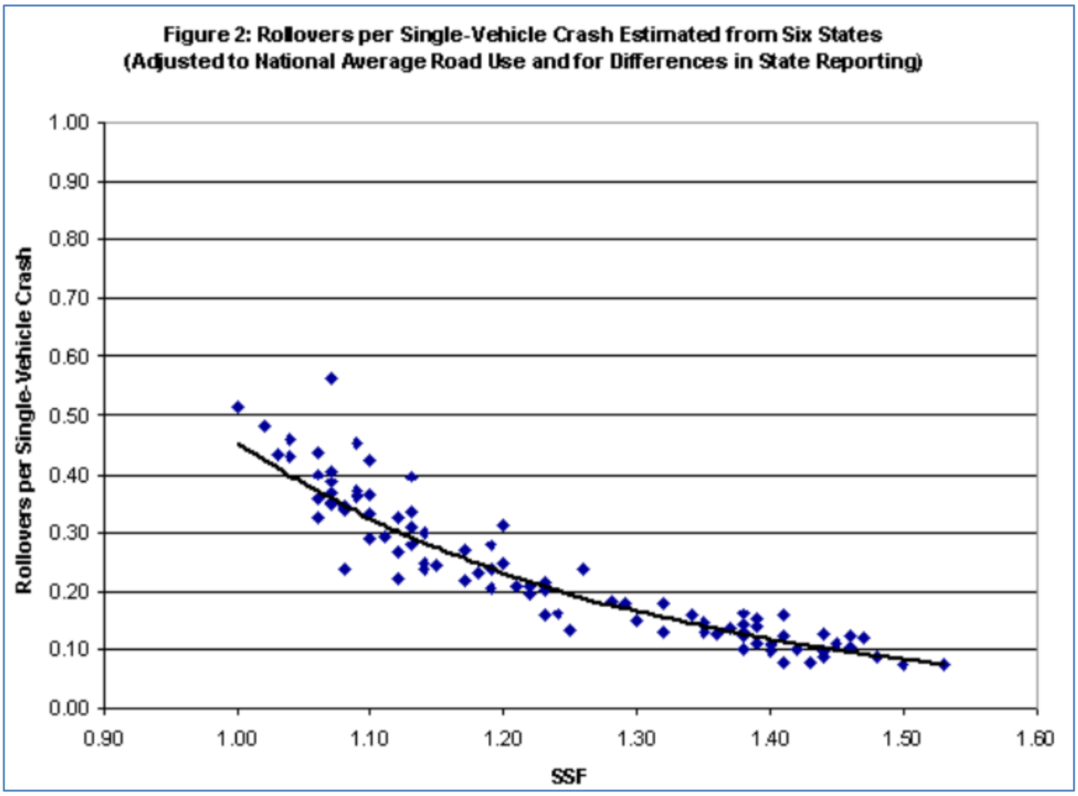

Figure 2: NHTSA data on rollovers per Single-vehicle crash estimated from Six states, adjusted for differences in road use or State reporting.
http://www.nhtsa.gov/cars/rules/rulings/rollfinal/index.html#roll12

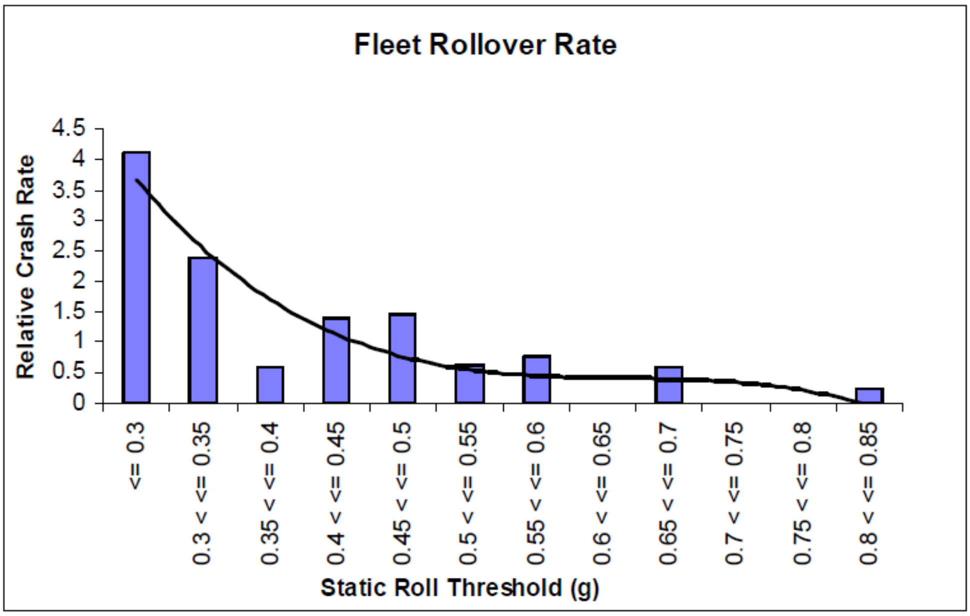

Figure 3: Relative crash rate as a function of SRT for heavy vehicles (DIER, 2006).

3.3.3 Tilt Table Ratio (TTR)

The definition of the Title Table Ratio (TTR) is provided in the NHTSA note (their Figure 1). It states that:

> *"While the SSF can be simply measured from a vehicle's geometric properties, a simple test of rollover resistance, which includes some effects of suspension and tyre displacement, is to place a vehicle entirely on a table which tilts about a longitudinal axis and raises one side of the vehicle higher than another. As the table continues to tilt, it eventually reaches an angle at which the high side tires lift from the table, and the vehicle rolls over if not restrained. The critical angle is called the Tilt Table Angle.*
>
> *The trigonometric function, tangent, of this angle is the Tilt Table Ratio (TTR), which is the ratio of the component of the tilted vehicle's weight which acts laterally to overturn it, to the component perpendicular to the table which resists overturning. For an idealized vehicle without suspension movements, the TTR is the same as the SSF. The suspension movements of actual vehicles reduce the TTR about 10 to 15 percent relative to the SSF."*

In Figure 4, as the tilt-table angle increases to angle **α**, at the point just before 2-wheel lift occurs about the vehicle's bottom tyres (point OP), the component of the vehicle weight

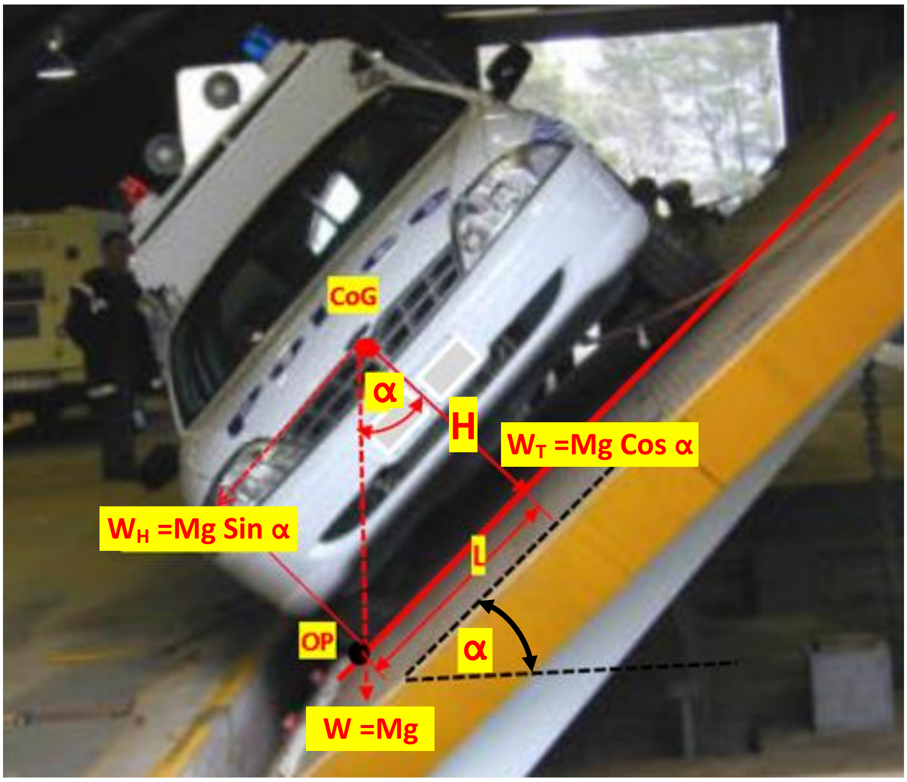

Figure 4: Tilt Table with vehicle at point of tip over, showing the gravitational forces acting, relationship between tilt table angle and the vehicle's CoG height and track width. (Tilt-Table test photo from Rechnitzer et al., 2002)

(force) acting through the vehicle's CoG acts to tip the vehicle over, is resisted by the component of the vehicle's weight acting perpendicular to the tilt table according to Equation 8:

$$W_{\mathrm{H}}H = W_{\mathrm{T}}L \qquad \textbf{Equation 8}$$

Hence, substituting for the force components shown in Figure 4:

$$(Mg\,Sin\,\alpha)\mathrm{H} = (Mg\,Cos\,\alpha)\mathrm{L} \qquad \textbf{Equation 9}$$

From Equation 9, tip over will occur at angle **α**, where:

$$\frac{Sin\,\alpha}{Cos\,\alpha} = Tan\,\alpha = \frac{L}{H} = \textit{Tilt Table Ratio} = TTR \qquad \textbf{Equation 10}$$

For the particular case of little or no suspension/ tyre movement[22], L = T/2 (i.e. half track width), thus Equation 9 becomes,

$$Tan\,\alpha = \frac{T}{2H} = SSF = TTR \qquad \textbf{Equation 11}$$

showing that the TTR equals the SSF.

3.3.4 SSF, TTR and equivalent lateral acceleration and tip over

From Equation 7, notably, at tip over the value $\frac{V^2}{gr}$ is the centripetal lateral acceleration in 'g', and equals $\frac{T}{2H}$, the SSF. From Equations 7 and 11, for the tilt-table angle at tip over in general the lateral acceleration (in 'g') at tip over can be determined using the following equation:

$$Tan\,\alpha = \textit{TTR (and SSF)} \qquad \textbf{Equation 12}$$

Thus using a tilt table, and measuring the angle at which the vehicle starts to tip, directly relates to a vehicle's stability characteristic either when traveling around a curve or on a slope.

The key question is how relevant are such static stability metrics as SSF and TTR to Quad bikes[23] and SSV used in different, off-road environments. The answer is very relevant as overturn can occur both on slopes and on level ground during a turn manoeuvre.

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[22] For cars, NHTSA states, tyre/suspension deflection decreases the TTR by 10% to 15%. It may be potentially more than this for ATVs or SSVs, depending on a specific vehicle's design. It is possible to identify this change from the tests carried out and reported in Part 2 of the QBPP focussing on Dynamic Handling.

[23] It is relevant to note here that Quad bikes are also referred to as ATV – i.e. All-Terrain Vehicles - a point which will be discussed in more detail in subsequent sections and Conclusions of this Report.

Such static stability parameters are particularly relevant to Quad bikes (and SSVs) as these vehicles are used (and promoted to be used) in a variety of terrains, including hilly and uneven ground and vegetation cover, which exposes them to a higher risk of rollover. Of course this is not the only factor that affects vehicle stability as other vehicle parameters such as vehicle suspension design, locked and unlocked differentials, tyre profiles, steering, etc., can affect the resulting dynamic stability and/or ability to deal with terrain variation in the intended operational environment. These effects are examined in the Dynamic Handling testing in Part 2 of this project.

3.4 The Relevance of 'Active Riding' to Rollover Risk Mitigation for Quad Bikes and the Static Stability Tests

'Active Riding' is promoted as a key part of Quad bike training and risk mitigation for rollover and handling by the Quad bike Industry. But there are no identified publications/reports worldwide which comprehensively quantify the benefits or effectiveness of Active Riding, for increased stability or crash risk reduction. The Authors have considered the effectiveness of Active Riding in previous work (Rechnitzer et al., 2003) albeit in a limited manner.

Active Riding has not been included in the Static Stability test program per se, but is examined in part in the Dynamic Handling tests. Further discussion of Active Riding will form part of the final report for this study on the completion of all tests, i.e. Parts 1 to 3.

In so far as Active Riding was considered in this part of the project (Part 1), the Static Stability testing undertaken factors in a full range of Quad bike and SSV static stability situations:

1. SSF by calculation.
2. Pitch static stability as per ANSI /SVIA 1-2010 for Quad bikes (ATVs).
3. TTR determined for the conditions:
    a. Baseline. No rider or load.
    b. With upright large rider.
    c. With upright large rider and maximum specified load capacity, with combinations of front, rear and front and rear full loads and OPDs depending on the vehicle type as follows:
        i. "Work" Quad bikes front, rear and front and rear full loads, and with OPDs.
        ii. "Rec/ Sports Quad bikes: no load or OPD (attachment provisions on these Quad bikes not available).
        iii. SSVS – rear full load provisions only.

The tests did not include, however, variable rider positions as may be used in Active Riding nor the inclusion of a pillion/passenger.[24] The static stability of a Quad bike with a rider, using Active Riding techniques, is likely to vary, and fall between that of the base line Quad bike and the Quad bike tested with the 95th % rider (dummy mass is 101 kg, and with tie down straps a total of 103 kg test mass).

The Authors suggest that a project be funded that examines and tests the effectiveness of the Active Riding style being promoted and taught at Quad bike training facilities. Similarly, a project be should also be considered where stability tests are carried out with a pillion/passenger to assess what the reduction would be in TTR in such circumstances when informing riders of such inappropriate behaviour. A number of fatality cases involved the death of a passenger being carried on a Quad bike designed for only one rider.

3.5 Static Stability Requirements from the Quad bike (ATV) and SSV Standards

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

The two main USA standards[25] relevant to Quad bikes and SSVs are, respectively:

1. **QUAD BIKES:** **ANSI /SVIA 1-2010: American National Standard for Four Wheel All-Terrain Vehicles.** Pub: American National Standards Institute (ANSI), and the Speciality Vehicle Institute of America (SVIA), 23/12/2010.

The only static stability requirement specified for Quad bikes in this standard is for pitch static stability (Kp). There are no lateral Static Stability, or Dynamic Handling testing requirements. Pitch static stability is set out in Section 9 of the Standard. It involves rotating the front of the Quad bike upwards (see Figure 5), and determining the angle at which it balances about its rear wheels. It also involves measuring geometric properties of the Quad bike such as wheelbase, weight distribution, CoG longitudinal position, rear axle height.

The formulae given to calculate Kp is:

$$K_P = \frac{L_1 \text{ Tan } \alpha}{L_1 + R_r \text{ Tan } \alpha} \qquad \textbf{Equation 13}$$

where L_1 is the projected distance from the rear axle to the CoG as shown in Figure 5, **α** is the tip angle and R_r is the vertical distance from the rear axle to the ground (approximately the wheel radius if it assumed the tyre does not distort relative to its distortion at the Quad bike's 'level' no load condition). The standard requires that Kp shall be at least 1.0.

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[24] Carrying of passengers on Quad bikes designed for only one rider (the majority of Quad bikes) is warned against on required and prominently affixed Quad bike warning labels, in Quad bike training courses, and in Quad bike owner's manuals and point of sale material supplied with all new Quad bike sales in Australia.

[25] A third standard may be relevant to some SSVs, but apparently not to the 16 test vehicle in this project: ANSI /OPEI B71.9-2012 American National Standard for Multi-Purpose Off-Highway Utility Vehicles.

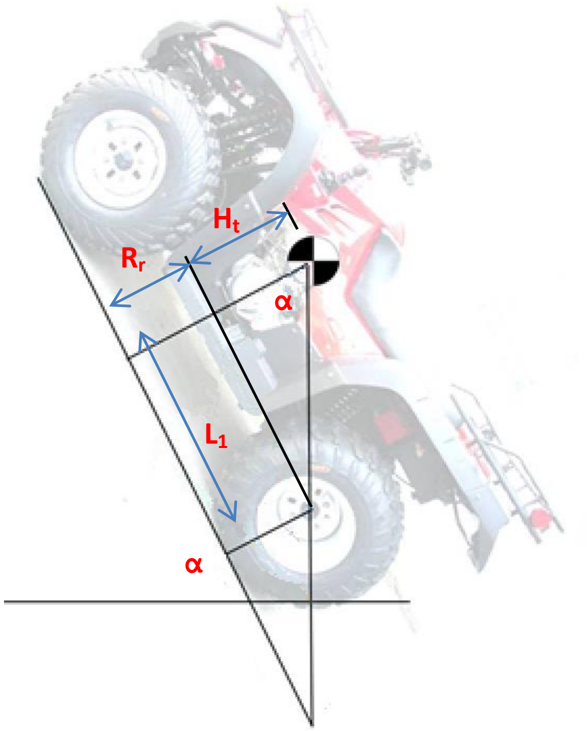

Figure 5: Tilt of vehicle at point of tip over, showing the geometric relationship for Kp. Note rear tyre is supported on flat surface in this instance.

A formula given to calculate Kp differs from that used in Equation 11 and presented in this report in that for the ANSI /SVIA 1-2010 tests the rear tyre is supported on a flat ground and the vehicle rotated. This is different to the pitch stability test using the tilt table for rear static stability as presented in this report where the rear wheel was supported on the inclined tilt table.

The pitch stability Kp was determined using ANSI /SVIA 1-2010 test methodology, in addition to the tilt tables tests, as part of the tests for the 16 production vehicles, and is reported as part of the results.

2. **SSVs: ANSI /ROHVA 1-2011: American National Standard for Recreational Off-Highway Vehicles**. American National Standards Institute (ANSI), and the Recreational Off-Highway Vehicle Association. July 2011.

Both static and Dynamic tests requirements are set out.

Lateral Stability requirements are specified in Section 8 of the Standard, and uses Tilt Table tests. It states:

> *All ROVs shall meet the lateral stability performance requirements listed in sections 8.1.4 and 8.2.3 when tested as described below. Tilt table tests shall be conducted in both the loaded configuration and operator and passenger configuration.*

The Clause 8.1 Tilt Table Test requirements include:

- The ROV shall be loaded such that a test occupant weight (98kg) or equivalent is placed in each seating position.
- The ROV rear cargo box is to be loaded to its specified capacity using appropriate amount of sand, distributed uniformly across the floor of the cargo box.
- The tilt table test is lateral.
- The stability of the vehicle shall be determined directly by slowly tilting the platform to:
  - Loaded Configuration – 24 degrees (44.5%)
  - Operator and Passenger Configuration – 30 degrees (57.7%).
- Acceptance of the lateral stability test shall require that at least one of the supporting tire or tires on the uphill side remain in contact with the surface.

Clause 8.2 Stability Coefficient (K_{st}) requirements

This specifies the lateral stability coefficient K_{st} to be >1. K_{st} is comparable to TTR, and is calculated for the unloaded condition, using the following formulae:

8.2.2 Calculation.

$$K_{st} = \frac{L\,t_2 + L_{cg}\,(t_1 - t_2)}{2LH_{cg}}$$

Where:

L_{cg}	Location of the cg forward of the rear axle
H_{cg}	Location of the cg above the ground plane
t_1	Front track width
t_2	Rear track width
L	Wheelbase

8.2.3 Performance Requirements. K_{st} shall be no less than 1.0.

For vehicles where the front and rear track are the same, this formula reduces to the familiar:

$$\boldsymbol{K_{st} = \frac{T}{2H}}$$

i.e. equivalent to the Static Stability Factor (see Equation 7).

Pitch Stability requirements are set out in Section 9 of the Standard, and use the Tilt Table method, and are for forward and rearward pitch stability.

- Loading is as per the lateral tilt table tests, i.e. with occupant and full rear load.
- The tilt table is tilted to a 28 degree (53.2%) gradient
- Performance Requirements. Acceptance of the pitch stability test shall require that at least one of the supporting tire or tires on the uphill side remain in contact with the surface.

Relevance of TTR and K_{st} to SSV stability assessment

This set out in Appendix *A8.2 Stability Coefficient* (page 62 of ANSI /ROHVA 1-2011) which in particular states that “*The TTA test is representative of a vehicle operating on a side slope”, i.e.*

> *“Both tilt-table angle (TTA)*[26] *and lateral-stability coefficient (K_{st}) are used. The TTA test is representative of a vehicle operating on a side slope. The vehicle state for these tests range from the operational but otherwise unloaded ROV to represent recreational use to the loaded ROV (not to exceed GVWR) to represent general utility use.*”

In addition it states that *“K_{st} serves as an indicator of level-terrain vehicle stability”*, i.e.

> *“Unlike an on-highway vehicle, ROVs are used in a variety of inconsistent, unpaved environments. Given the number of operating variables, meaningful dynamic stability testing that is repeatable on off-highway terrain is impossible using current test methods and technology. For this reason, K_{st} serves as an indicator of level-terrain vehicle stability.”*

This means that the static stability based measurements being used in this project (TTR) are considered by the ANSI /ROHVA 1-2011 standard as appropriate indicators of SSV operating stability on both slopes and level ground.

[26] *TTR = Tan (α)*

4 THE STATIC STABILITY TEST PROGRAM AND RESULTS

The Static Stability testing using the tilt table was carried out at Crashlab. The full Crashlab Test Report, the methods used and all test results for each of the sixteen production vehicles tested are provided in Attachment 2.

This section of the report highlights the key Static Stability results and discussion of the results. This then leads to the development of the Static Stability Overall Rating Index for the seventeen vehicles tested. The actual Star Rating system developed will only apply to the completed test program, incorporating the Static Stability tests, the Dynamic Handling tests and the Rollover Crashworthiness test components, with some other features.

The Static Stability testing involved a comprehensive set of approximately 318 tests for the 16 production vehicles, as set out in Tables 3 and 4. Table 4 shows what tests were carried out with the three different model OPDs.

The test results are presented in terms of the measured maximum Tilt Table angle at point of vehicle two wheel lift for the test condition, and the Tilt Table Ratio (TTR). TTR is given by the following equation, as derived in Equations 10 and 11 previously:

$$TTR = Tan\ \alpha \qquad \textbf{Equation 14}$$

Tilt-Table Tests	Models	Baseline	ATD	ATD+Front Load	ATD+Rear Load	ATD +Front & Rear Load
• Lateral • Rear Pitch • Forward Pitch	8 Work Quad bikes	Yes	Yes	Yes	Yes	Yes
	3 Sports/ Rec Quad bikes	Yes	Yes	-	-	-
	5 SSVs	Yes	Yes	-	Yes	-

Table 3: Matrix of Tilt Table test for the 16 production vehicle models.

Tilt-Table Tests	Models	Baseline	ATD	ATD+Front Load	ATD+Rear Load	ATD +Front & Rear Load
• Lateral • Rear Pitch • Forward Pitch	Lowest Roll Stability Quad bike	Yes	Yes	Yes	Yes	Yes
	Median Roll Stability Quad bike	Yes	Yes	Yes	Yes	Yes
	Highest Roll Stability Quad bike	Yes	Yes	Yes	Yes	Yes

Table 4: Matrix of Tilt Table test with 3 OPD models.

The lower the TTR number, the less stable the vehicle is in the test direction (lateral roll, rear or forward pitch).

The full matrix of the detailed results for each of the 16 production vehicles in terms of peak Tilt Table angles and TTR for lateral roll, forward pitch and rear pitch and are given in Tables 2, 3 and 4, respectively, in the Crashlab report, provided in Attachment 1.

The following sections analyse the TTR results for each of the lateral roll, forward pitch and rear pitch tests, the three vehicle categories and the different maximum load combinations.[27]

Note that the SSV testing was conducted with a 95th % adult male larger weight ATD only, and not with a combination of driver and passenger dummy. For lateral roll this is the worst case scenario for stability (i.e. driver on lower side), and similarly for rear pitch. For forward pitch having two occupants may slightly reduce the forward pitch TTR, but as these values are already high, a small reduction would unlikely be significant.

4.1 TTR Results for Lateral Roll Static Stability Tests

The following figures and tables provide a summary of the TTR results for all the vehicles, vehicle categories and maximum load combinations in the case of lateral roll stability tests.

Table 5 summarises the range of the TTR test results for lateral roll for the three vehicle categories and loading combination.

Load condition	Vehicle type	Tilt Table Ratio (TTR)	Tilt angle
Base line (no operator, no load)	Agricultural quad bikes (8) Recreational quad bikes (3) Side by side vehicles (5)	TTR = 0.72 to 0.82 TTR =0.93 to 1.10 TTR =0.85 to 1.01	35.7˚ to 39.2˚ 42.8˚ to 47.6˚ 40.2˚ to 45.3˚
Operator only	Agricultural quad bikes (8) Recreational quad bikes (3) Side by side vehicles (5)	TTR =0.46 to 0.60 TTR =0.56 to 0.78 TTR =0.65 to 0.96	24.5˚ to 30.8˚ 29.2˚ to 37.8˚ 32.9˚ to 43.8˚
Operator plus rear load	Agricultural quad bikes (8) Side by side vehicles (5)	TTR =0.44 to 0.56 TTR =0.64 to 0.83	23.9˚ to 29.4˚ 32.5˚ to 39.8˚
Operator plus front load	Agricultural quad bikes (8)	TTR =0.43 to 0.57	23.4˚ to 29.6˚
Operator plus front load and rear load	Agricultural quad bikes (8)	TTR =0.41 to 0.55	22.2˚ to 29.0˚

Table 5: Lateral Roll TTR Summary of Results, by vehicle type and maximum load condition (from Table 5 Crashlab Report). 95th % adult male ATD used except for Can-am DS90X youth model where 5th % adult female ATD used.

[27] Manufacturers specified maximum loads.

Table 6 re-arranges the TTR results from Table 5, to enable comparison of the change in TTR values for each vehicle category with different maximum load combinations.

Figure 6 shows in bar chart form the TTR results for lateral roll for all of the vehicles and maximum load configurations, including OPDs.

	TTR Load Condition					
Vehicle type	**Baseline**	**Operator only**	**Operator plus rear load**	**Operator plus front load**	**Operator plus front and rear load**	**TTR Maximum Reduction from base line %**
Work Quad bike	0.72 to 0.82	0.46 to 0.60	0.44 to 0.56	0.43 to 0.57	0.41 to 0.55	43%
Sports/ Rec Quad bike	0.93 to 1.10	0.56 to 0.78	na	na	na	40%
SSV	0.85 to 1.01	0.65 to 0.96	0.64 to 0.83	na	na	25%

Table 6: Lateral Roll TTR Summary of Results. Comparison by vehicle type category and change in TTR with maximum loading (from Table 5 Crashlab Report). 95th PAM ATD used except for Can-am DS90X youth model where 5th PAF ATD used.

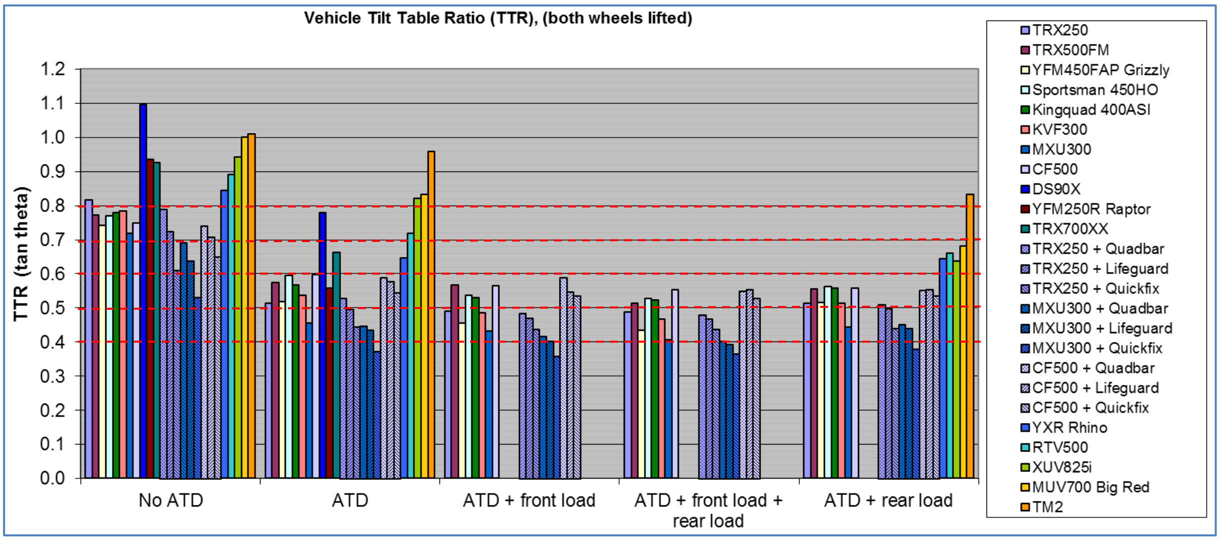

Figure 6: TTR results for Lateral Roll, all vehicles, all tests including OPDs. 95th PAM ATD used except for Can-am DS90X youth model where 5th PAF ATD used.

The work Quad bikes group shows the lowest static stability factors (TTR), particularly when loaded with a fixed rider dummy and maximum load. For the work Quad bikes, while the base line TTR ranges from 0.72 to 0.82 it drops significantly with a rider and when fully loaded, down to a range 0.41 to 0.55, a reduction of up to 40%. These low TTRs highlight the effect of the weight of the rider and full load on reducing Quad bike static stability. These low values highlight the lower resistance to rollover of these vehicles on steeper slopes and hilly terrain, and likely inappropriateness (i.e. not Fit For Purpose) in such environments.

With a large rider, for the least stable Quad bike based on TTR, the potential slope angles for rollover reduce significantly down to about 25 degrees.

With a large rider and maximum manufacturer specified load front and rear, stability based on TTR is reduced further. For the least stable Quad bike, based on these tests, potential slope angles for rollover reduce further down to about 22 degrees.

In regard to discrimination in TTR values between Quad bikes, as shown in Table 5, Table 6 and Figure 6, this is much less marked than the difference between the Quad bikes and SSV, with SSVs being substantially higher. It should also be recognised that the rear load capacities (as tested), are much higher for the SSVs than the Quad bikes.

The effect of OPDs was varied. The lightweight Quadbar (about 8.5kg) has a small and not significant effect on the stability of the Quad bikes, of less than 2%, as most of the mass is distributed from the tow coupling upwards. The heavier Lifeguard (about 14.8kg) also has a small effect on stability of less than 4%, where the mass is applied at the cargo rack, which is above the CoG of the Quad bike. However the Quickfix (full 4 post canopy, 30kg) reduced the SSF by about 13% with rider, and about 8% fully loaded and with a large rider. All of this mass is applied well above the CoG of the Quad bike.

The SSVs have higher TTRs than work Quad bikes, some by up to 40 to 60%. The SSVs with the lowest TTR are more stable (i.e. have a higher TTR) than the highest stability work Quad bike, fully loaded or unloaded. Apart from the CoG height the key factor affecting lateral stability is the larger track width of the SSVs with increasing stability (i.e. higher TTR) compared with the lower stability Quad bikes (see vehicle data in Attachment 2 in the Crashlab Report, Appendix D). For example, for the SSVs, the Honda MUV700 and John Deere Gator XUV825i track width is almost 1.3m, and the Tomcar TM2 is 1.49m. This compares with the lower stability Quad bikes with average track width of just under 0.8m.

In general, the sports/ recreational Quad bikes have higher TTRs than the work Quad bikes with a large rider, as a result of a combination of their having a lower CoG height and/or wider track width. Active Riding can play a part in increased stability, however effectiveness is contingent on rider skill, age, weight relative to the Quad bike, etc., and to the Authors' knowledge this has not been comprehensively evaluated, as discussed previously.

4.2 TTR Results for Forward Pitch Static Stability Tests

The following figures and tables provide a summary of the TTR results for all the vehicles, vehicle categories and maximum load combinations in the case of forward pitch tests.[27]

Figure 7 shows in bar chart form the TTR results for forward pitch for all of the vehicles and load configurations, including OPDs.

Table 7 summarises the range of the TTR test results for forward pitch for the three vehicle categories and maximum loading combinations.

Load condition	Vehicle type	Tilt Table Ratio (TTR)	Tilt angle
Base line (no operator, no load)	Agricultural quad bikes (8) Recreational quad bikes (3) Side by side vehicles (5)	TTR = 1.12 to 1.34 TTR = 1.31 to 1.39 TTR = 1.89 to 2.18	48.3° to 53.2° 52.6° to 54.3° 62.1° to 65.4°
Operator only	Agricultural quad bikes (8) Recreational quad bikes (3) Side by side vehicles (5)	TTR =0.94 to 1.08 TTR =0.97 to 1.10 TTR =1.70 to 1.88	43.2° to 47.1° 44.2° to 47.6° 59.5° to 62.0°
Operator plus rear load	Agricultural quad bikes (8) Side by side vehicles (5)	TTR =0.97 to 1.10 TTR =1.81 to 1.95	44.0° to 47.8° 61.1° to 62.8°
Operator plus front load	Agricultural quad bikes (8)	TTR =0.82 to 0.94	39.3° to 43.1°
Operator plus front load and rear load	Agricultural quad bikes (8)	TTR =0.89 to 1.02	41.6° to 45.5°

Table 7: Forward Pitch TTR and Tilt Table angle; Summary of Results, by vehicle type and maximum load condition (from Table 6 in Crashlab Report – Attachment 2). 95th PAM ATD used except for Can-am DS90X youth model where 5th PAF ATD used.

	TTR Load Condition					
Vehicle type	**Baseline**	**Operator only**	**Operator plus rear load**	**Operator plus front load**	**Operator plus front and rear load**	**TTR Maximum Reduction from base line %**
Work Quad bike	1.12 to 1.34	0.94 to 1.08	0.97 to 1.10	0.82 to 0.94	0.89 to 1.02	30%
Sport/Rec Quad bike	1.31 to 1.39	0.97 to 1.10	na	na	na	26%
SSV	1.89 to 2.18	1.70 to 1.88	1.81 to 1.95	na	na	14%

Table 8: Forward Pitch TTR Summary of Results. Comparison by vehicle type category and change in TTR with maximum loading (from Table 6 in Crashlab Report – Attachment 2). 95th PAM ATD used except for Can-am DS90X youth model where 5th PAF ATD used.

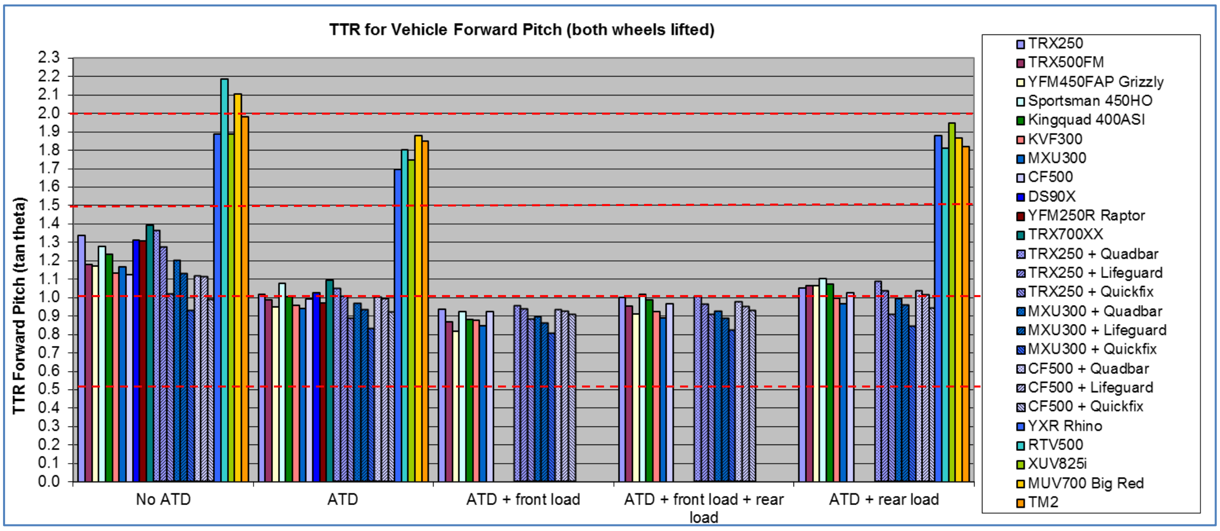

Figure 7: TTR results for Forward Pitch, all vehicles, all tests including OPDs. 95th PAM ATD used except for Can-am DS90X youth model where 5th PAF ATD used.

Table 8 re-arranges the TTR results from Table 7, to enable comparison of the change in forward pitch TTR values for each vehicle category with different full load combinations.

For all of the vehicles front pitch stability is significantly higher than lateral stability, particularly for the SSVs. This is largely a function of vehicle wheel base and CoG position (see Attachment 2, Crashlab Report, Appendix D). The SSVs' wheelbase range from 1.8m to 2.05m, compared with the much shorter wheelbase for the work Quad bikes of 1.13m to 1.28m.

For the work Quad bikes, the base line TTR ranges from 1.12 to 1.34 and it reduces with a large rider and when fully loaded, down to a range 0.89 to 1.02, a reduction of up to 30%. Although these TTR values still represent steep slopes of over 39 degrees when loaded, however forward pitch rollover can be adversely affected by dynamic effects, e.g. brake application or hitting depressions and rocks.

For the work Quad bikes, in regard to discrimination in TTR values, the models have a difference in pitch stability of up to 16% (Table 7). This is a much smaller difference than the up to 30% in lateral stability.

For the Quad bikes with OPDs, both the lightweight Quadbar and the slightly heavier Lifeguard have minor effects (generally positive) on forward pitch stability. The Quickfix unit being heavier (30kg) and higher, has a more pronounced effect compared to the other OPDs on static stability, reducing the TTR by about 14% in forward pitch.

For the SSVs the front pitch TTR values are high, including fully loaded (rear load) ranging from 1.81 to 1.95, almost double that for the Quad bikes.

The sports/ recreational Quad bikes showed similar TTRs to the work Quad bikes, ranging from 0.97 to 1.10 with a large rider. Although these TTR values still represent steep slopes of over 44 degrees with a large rider, however forward pitch rollover can be adversely affected by dynamic effects, e.g. hitting depressions and rocks. This will be evaluated as part of the Dynamic Handling test program. Active Riding can also play a part in increased front pitch stability.

4.3 TTR Results for Rearward Pitch Static Stability Tests

The following figures and tables provide a summary of the TTR results for all the vehicles, vehicle categories and maximum load combinations in the case of rearward pitch static stability. [27]

Figure 8 shows in bar chart from the TTR results for rearward pitch for all of the vehicles and maximum load configurations, including OPDs.

Table 9 summarises the range of the TTR test results for rearward pitch for the three vehicle categories and maximum loading combinations.

Table 10 re-arranges the TTR results from Table 9, to enable comparison of the change in rearward pitch TTR values for each vehicle category with different maximum load combinations.

For all of the vehicles, rear pitch static stability is higher than lateral static stability, particularly for the SSVs, unloaded. Rear pitch static stability is lower than forward pitch static stability, particularly when fully loaded. This is largely a function of the rear loading. The vehicle wheel base and CoG position (see Attachment 2 Crashlab Report, Appendix D), shows the SSVs' wheel base ranging from 1.8m to 2.05m, compared with the much lower wheelbase for the work Quad bikes of 1.13m to 1.28m.

However with rear full load, as would be expected rear stability reduces significantly, by up to 40%.

Load condition	Vehicle type	Tilt Table Ratio (TTR)	Tilt angle
Base line (no operator, no load)	Agricultural quad bikes (8) Recreational quad bikes (3) Side by side vehicles (5)	TTR = 1.13 to 1.31 TTR = 1.17 to 1.32 TTR = 1.08 to 1.66	48.4° to 52.7° 49.6° to 52.9° 47.1° to 58.9°
Operator only	Agricultural quad bikes (8) Recreational quad bikes (3) Side by side vehicles (5)	TTR = 0.78 to 0.95 TTR = 0.73 to 0.90 TTR = 1.04 to 1.49	37.9° to 43.6° 36.3° to 41.9° 46.0° to 56.2°
Operator plus rear load	Agricultural quad bikes (8) Side by side vehicles (5)	TTR = 0.62 to 0.79 TTR = 0.77 to 1.01	31.8° to 38.4° 37.5° to 45.4°
Operator plus front load	Agricultural quad bikes (8)	TTR = 0.81 to 1.01	39.0° to 45.4°
Operator plus front load and rear load	Agricultural quad bikes (8)	TTR = 0.68 to 0.82	34.2° to 39.5°

Table 9: Rearward Pitch TTR and Tilt Table angle; Summary of Results, by vehicle type and maximum load condition (from Table 7 Crashlab Report). 95th PAM ATD used except for Can-am DS90X youth model where 5th PAF ATD used.

	TTR Load Condition					
Vehicle type	**Baseline**	**Operator only**	**Operator plus rear load**	**Operator plus front load**	**Operator plus front and rear load**	**TTR Maximum Reduction from base line %**
Work Quad bike	1.13 to 1.31	0.78 to 0.95	0.62 to 0.79	0.81 to 1.01	0.68 to 0.82	40%
Sport/Rec Quad bike	1.17 to 1.32	0.73 to 0.90	na	na	na	37%
SSV	1.08 to 1.66	1.04 to 1.49	0.77 to 1.01	na	na	39%

Table 10: Rearward Pitch TTR Summary of Results. Comparison by vehicle type category and change in TTR with maximum loading (from Table 7 Crashlab Report). 95th PAM ATD used except for Can-am DS90X youth model where 5th PAF ATD used.

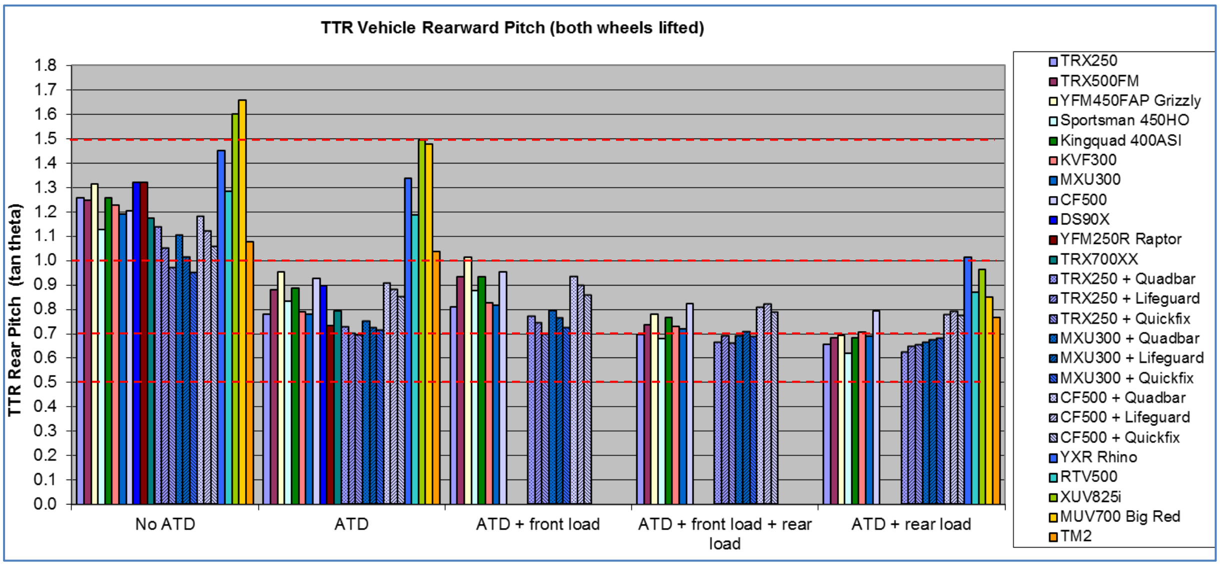

Figure 8: TTR results for Rearwards Pitch, all vehicles, all tests including OPDs. 95th PAM ATD used except for Can-am DS90X youth model where 5th PAF ATD used.

For the work Quad bikes, the base line TTR ranges from 1.13 to 1.31 and reduces with a rider and when fully loaded, down to a range 0.68 to 0.82, a reduction of up to 40%. Although these TTR values still represent steep slopes of over 34 degrees when fully loaded, the drive (or braking when reversing downhill) torque on the rear wheels can reduce the effective TTR lowering the rear pitch rollover resistance.

For the work Quad bikes, in regard to discrimination in TTR values, the models have a difference in rear pitch static stability of up to 20% (Table 10). This is a smaller difference than the up to 30% in lateral static stability measured.

Regarding the effect of OPDs, the lighter weight Quadbar reduces the rear pitch TTR by up to about 7% with a large rider for the lighter Quad bikes. The heavier Lifeguard reduces rear pitch stability (TTR) by up to about 10% with a rider for the lighter Quad bikes; the Quickfix (full 4 post canopy) reduced the rearward pitch static stability by up to 11% with a large rider and maximum rear load.

For the SSVs the rear pitch TTR values vary significantly between the various SSV models, and are much lower, at almost half: from 1.81-1.95 down to 0.77-1.01, when fully loaded. As the SSVs only carry rear load, and have a relatively high rated loaded capacity (181kg to 454kg; see Attachment 2 Crashlab Report, Appendix D), rear pitch static stability is significantly reduced by up to 39%, down to the range 0.77 to 1.01.

The sports/ recreational Quad bikes showed similar TTRs to the work Quad bikes, ranging from 0.73 to 0.90 with a rider. Although these TTR values still represent fairly steep slopes of over 36 degrees with rider, rear pitch stability can be adversely affected by drive (or braking when reversing downhill) torque on the rear wheels, which can further increase the risk of rear pitch stability. Active Riding can also play a part in increased rear pitch stability.

As demonstrated with motor vehicles, there is potential opportunity with active safety systems using electronic control systems. For example, the possibility of engine management systems that respond to tilt angle sensor input, to control rear wheel torque and induced rear pitch-over crashes. This is beyond the scope of this study. Research is being carried out in France and elsewhere exploring the possibilities of such systems (Richier et al., 2011).

4.4 Comparison of prototype Quad bike to other vehicles

The workplace Quad bike group show the lowest stability factors (TTRs), particularly when loaded with a fixed rider dummy and maximum load, dropping down to a TTR range of 0.41 to 0.55. However, Table 11 shows that the wider track prototype Quad bike has a much higher lateral TTR (on average 50% higher) than all of the Quad bikes and is comparable with some of the SSVs.

	TTR and Load Condition						
Vehicle type	Test	Baseline	Operator only	Operator plus rear load	Operator plus front load	Operator plus front and rear load	TTR Maximum Reduction from base line %
Work Quad	Lateral roll	0.72 to 0.82	0.46 to 0.60	0.44 to 0.56	0.43 to 0.57	0.41 to 0.55	43%
	Rear Pitch	1.13 to 1.31	0.78 to 0.95	0.62 to 0.79	0.81 to 1.01	0.68 to 0.82	40%
	F'ward Pitch	1.12 to 1.34	0.94 to 1.08	0.97 to 1.10	0.82 to 0.94	0.89 to 1.02	30%
SSV	Lateral roll	0.85 to 1.01	0.65 to 0.96	0.64 to 0.83	na	na	25%
	Rear Pitch	1.08 to 1.66	1.04 to 1.49	0.77 to 1.01	na	na	39%
	F'ward Pitch	1.89 to 2.18	1.70 to 1.88	1.81 to 1.95	na	na	14%
Prototype Quad bike	Lateral roll	0.99	0.81	0.76	0.79	0.75	24%
	Rear Pitch	1.19	0.94	0.85	0.97	0.85	28%
	F'ward Pitch	1.18	1.01	1.06	0.94	0.96	11%
Sports/ Rec Quad bike	Lateral roll	0.93 to 1.10	0.56 to 0.78	na	na	na	40%
	Rear Pitch	1.17 to 1.32	0.73 to 0.90	na	na	na	37%
	F'ward Pitch	1.31 to 1.39	0.97 to 1.10	na	na	na	26%

Table 11: Tilt Table TTR Summary of Results. Comparison by vehicle type category and change in TTR with maximum loading. 95th PAM ATD used except for Can-am DS90X youth model where 5th PAF ATD used.

4.5 Comparison of the TTR Results with the ANSI/SVIA 1-2010 Standard for Quad bikes (ATVs) and the ANSI-ROHVA 1-2011 Standard for SSVs

Table 12 sets out the Standards requirements for lateral roll and forward and rearward pitch stability, and compares these with the actual Tilt Table results.

For the Quad bikes, the ANSI/SVIA Standard has no lateral stability requirement. However, the Authors consider that in the absence of such requirements it is useful to compare requirements of ANSI/ROHVA 1-2011 for SSVs for Quad bikes as well. Although the Quad bike and SSVs are different vehicle types, they operate in similar environments, and as four wheeled vehicles have similar stability demand.

In regard to the ANSI/SVIA Standard's Kp requirement for Quad bikes, these were measured by Crashlab according to the recommended test procedure in ANSI/SVIA Standard and found to range from 1.3 to 1.5, all complying with the ANSI/SVIA 1-2010 requirement of Kp>1.0.

However, in comparison, the rear pitch tilt table test results (TTRs) showed a much lower value for rear pitch stability, which identifies that the rear pitch stability of these vehicle should be higher. Thus this would suggest that the ANSI requirement of Kp = 1.0 are too low, and should be further investigated as to adequacy in regard to rear rollover injury prevention.

The SSVs comply with ANSI/ROHVA 1-2011 requirements for Kst (see Attachment 2 Crashlab Report, Appendix D), as do the Sports/ Rec Quad bikes; but the work Quad bikes would not and nor are they required to according to the ANSI/SVIA 1-2010 standard for Quad bikes (ATVs).

The SSVs easily meet the lateral and pitch TTR requirements, strongly suggesting the Standard's requirements are too low. Some Quad bikes would also just meet these lateral TTR requirements, some would not. All the Quad bikes, although not required to meet the ANSI/ ROHVA 1-2011 standard, would meet the forward and rear pitch stability requirements from ANSI/ ROHVA, also indicating the Standard's requirements appear to be too low.

The Authors note that the CPSC (2009) have also identified that K_{st} is too low and they recommend a value of at a minimum in the 1.03 to 1.45 SSF range.

> *"The SSF values for the ROV models (with 2 occupants) tested by CPSC staff ranged from 0.84 to 0.92, which is far lower than the range for automobiles. CPSC staff believes that a SSF range of 0.84 to 0.92 is inadequate (too low) for a vehicle that is specifically designed to traverse conditions, such as uneven terrain and slopes, that present an even greater rollover hazard to vehicles than level on-road conditions."*

> *"CPSC staff does not believe the requirements in Section 8. Lateral Stability are adequate to address vehicle rollover. CPSC staff believes that the lateral stability requirement for ROVs should be in an occupied configuration, and at a minimum, should be in the 1.03 to 1.45 SSF range."*

Standard	Requirements- Lateral Roll	Requirements -Rear Pitch and Forward Pitch
ANSI/SVIA 1-2010 for ATVs (Quad bikes)	nil	Kp =1.0 Actual measured results give Kp from 1.3 to 1.5 (refer Attachment 2 Appendix D)
ANSI-ROHVA 1-2011 for SSVs	K_{st} =1.0, vehicle geometry Tilt Table: Loaded 24°; TTR =0.45 Occupants 30°; TTR =0.58	Tilt Table: Loaded 28°; TTR =0.53
Work Quad bikes (not required to comply with ANSI_ROHVA 1-2011)	K_{st}, would not comply. Tilt Table: Some would comply, some would not to ANSI_ROHVA.	Tilt Table TTR: All would comply to ANSI_ROHVA.
Sports/ Rec Quad bikes (not required to comply with ANSI_ROHVA 1-2011)	K_{st}, yes. Tilt-Table: two would comply, one would would not to ANSI_ROHVA.	Tilt Table TTR: All would comply to ANSI_ROHVA
SSVs	K_{st} - comply. All would comply with tilt-table TTR requirements	K_{st} - comply. All would comply with tilt-table TTR requirements

Table 12: Comparison of Stability Requirements from ANSI Standards for Quad bikes (ATVs) and SSVs, with Tilt Table Test Results.

5 STATIC STABILITY OVERALL RATING INDEX FOR THE 17 TEST VEHICLES

5.1 Basis of the Static Stability Overall Rating Index

The Static Stability Overall Rating Index is one of the three major test components of the ATVAP Star rating system:

1. Static Stability Tests
2. Dynamic Stability Tests
3. Crashworthiness Tests

In this section, the basis of the proposed Static Stability Overall Rating Index is developed. It is based on the Tilt Table Ratio (TTR) from all the tests, for each vehicle.

It is important to highlight that the Static Stability Overall Rating Index is a relative rating index which compares one vehicle with another. As such no one vehicle is being disadvantaged against another as the same criteria and weighting is applied to all vehicles.[28] Preliminary parametric analyses of the effect of any weighting variations indicate that the relative Static Stability Overall Rating Index (of one vehicle compared with another) is relatively insensitive to such variations.

The stability indices are firstly based on the TTR values for each of three tilt test directions, by summing and then averaging the TTR values for each loading combination within those test directions.

1. Lateral Roll
2. Forward Pitch
3. Rear Pitch

The final Static Stability Overall Rating Index for each vehicle is then derived from weighted average TTR values for each of the three test directions, as will be described subsequently.

Two different final Static Stability Overall Rating Index systems will be considered.

Static Stability Overall Rating Index - System 1: For vehicles carrying loads as well as the operator.[28]

SSR 1 =∑ TTR for (Baseline+ATD+all load combinations) ÷ (No. of tests)

For work Quad bikes

SSR 1_{WQ} =∑ TTR for (Baseline+ATD+Front load+Rear load+Front & rear load) ÷ (5)

For SSVs

SSR 1_{SSV} =∑ TTR for (Baseline+ATD+Rear load) ÷ (3)

[28] All loads are maximum loads to the manufacturer's specification. For ATD the 95th PAM dummy was used for all vehicles except for the Can-am DS90X youth model where a 5th PAF dummy used.

Static Stability Overall Rating Index - System 2: For vehicles with rider/ driver only, no other loads being carried.[28]

SSR 2 =∑ TTR for (Baseline+ATD) ÷ (2)

Static Stability Overall Rating Index - System 1 enables Static Stability Indices to be compared for the 14 vehicles that can carry loads: the 8 work Quad bikes, 1 prototype Quad bike and 5 SSVs. It uses the baseline TTR (i.e. unloaded and no rider) plus the TTR with the large rider or driver, plus the TTRs for all maximum load combinations.

Static Stability Overall Rating Index - System 2 enables Static Stability Indices to be compared for all the 16 production vehicles if they are just being used to travel between locations (and not for load carrying). It uses the baseline TTR (i.e. unloaded and no rider) plus the TTR with the large rider or driver.

5.1.1 Assumed risk exposure

It is important to note that the baseline TTR is also used in the Static Stability Overall Rating Index as its inclusion reflects for the Quad bikes, that the TTR with a rider will range somewhere between the baseline alone and baseline plus larger rider condition. This is because the tests were conducted for the heavier 95th %ile adult male rider weight, and with lighter riders the TTR will be higher in most cases. It also reflects some effect of so called Active Riding in some situations, which through body weight shift in position, could move the TTR to some degree back towards the higher baseline value.

Furthermore, by also using all of the TTR maximum load combinations, with the base line TTR and the baseline plus operator TTR, this reflects a measure of exposure for the vehicle usage. That is, implicit in this method of analysis, i.e. the exposure for each vehicle type is assumed to be approximately:

Assumed Risk Exposure time for Static Stability Overall Rating Index - System 1:

Assumed risk exposure time for work Quad bikes:

- 20% with lighter rider or some form of Active Riding;
- 20% with heavy rider;
- 20% with heavy rider plus full front load;
- 20% with heavy rider plus full rear load;
- 20% with heavy rider plus full front and rear load;

Risk exposure time for SSVs

- 33% of with lighter driver;
- 33% of with heavy driver;
- 33% of with heavy driver plus full rear load;

Assumed Risk Exposure time for Static Stability Overall Rating Index - System 2:

Assumed exposure time for work Quad bikes and Sports/ Recreational Quad bikes:

- 50% with lighter rider or some form of Active Riding;
- 50% with heavy rider;

Risk exposure time for SSVs

- 50% of with lighter driver;
- 50% of with heavy driver;

Due to the very limited exposure data on Quad bikes and SSV usage in Australia, the Authors consider that the above usage distribution of weightings represents a reasonable allocation until such time that Australian exposure data becomes available. Moreover, variations of these weightings appear to not affect the relative rating of the Static Stability Overall Rating Index.

5.1.2 Standardising the TTR values for the three test directions

To provide similar relative magnitudes for the indices for each of the three test directions, in the spread sheet of the TTR test results, each TTR value was normalised against a relatively high TTR value as follows:

- Lateral Roll: Maximum Index for TTR =1.0. Tan(45°) = 1.0
- Forward Pitch: Maximum Index for TTR =2.0. Tan (63.4°) = 2.0
- Rearward Pitch: Maximum Index for TTR =1.75. Tan (60.2°) = 1.75

Thus each TTR index value is adjusted by dividing by the relevant factor of 1.0, 2.0 and 1.75, respectively. These values are proposed by the Authors as benchmark reference values for lateral roll, forward pitch and rearward pitch respectively. These benchmark values were achieved (or nearly achieved) by those vehicles displaying the highest TTR stability measures, in some loading conditions. While these benchmark values could be argued as to basis, the Authors consider based on all available information as discussed in this report, and subject to further research and field evaluation, that they provide a reasonable starting point for desired stability value benchmarks.

5.1.3 Weighting of the Static Stability Overall Rating Index for roll direction incidence frequency

To take into account the different relative incidence of lateral roll, forward pitch and rear pitch rollovers, a relative weighting of 2:1:1 was assigned. The final Static Stability Overall Rating Index is determined by summing the normalised points for the three tilt-table test directions, but weighted in the ratio of 50% lateral roll, 25% forward pitch and 25% rear pitch. The Weighted Index has a maximum value[29] of 20.

The weighting factors used at the most basic level are founded on the geometric characteristics of the vehicles and reflect that lateral roll can occur in two directions (left and right) compared with one each for forward and rearward pitch. Hence, the relevant ratio of 2:1:1.

[29] It is noted that where a test vehicle exceeds the normalising value of 1.0, 2.0 and 1.75 respectively, a slightly higher score than 20.0 can be achieved theoretically.

As there is very limited data to date from the Quad bike rollover incident databases on rollover direction, this was considered by the Authors not sufficiently reliable to base the weighting factors on. Moreover, as was previously discussed, it is important to highlight that the Static Stability Overall Rating Index is a relative rating index which compares one vehicle with another. As such no one vehicle is being disadvantaged against another as the same criteria and weighting is applied to all vehicles. Preliminary parametric analyses of the effect of any weighting variations indicate that the relative Static Stability Overall Rating Index (of one vehicle compared with another) is relatively insensitive to such variations.

5.2 The Static Stability Overall Rating Index for Each Vehicle

The **Static Stability Overall Rating Index - System 1** with loads, for the 8 work production Quad bikes and 5 production SSVs is set out in Table 13 and Figure 9. The production Sports/ Rec Quad bikes do not carry load and are included in System 2 (no loads).

The **Static Stability Overall Rating Index - System 2** no loads, for the 8 work production Quad bikes, 3 production Sports/ Rec Quad bikes and the 5 production SSVs is set out in Table 14 and Figure 10.

5.3 Observations from the two Static Stability Overall Rating Index Systems

From these index results the following observations are made:

1. The Static Stability Overall Rating Index - System 1 (with loads): 13 production vehicles

This Static Stability Overall Rating Index is intended for vehicle stability comparison in the work environment or other uses where the vehicles carry loads as part of their usage.

The SSVs all have notably higher indices than the work Quad bikes, with indices ranging from 15.3 to 17.1, compared with 9.7 to 11.3 for the work Quad bikes.

2. The Static Stability Overall Rating Index - System 2 (with rider but no loads): 16 production vehicles

This Static Stability Overall Rating Index is intended for vehicle stability comparison in environments or other uses where the vehicles do not carry loads, but are used for travel or mobility work tasks only, e.g. herding cattle or sheep or accessing farm areas. The vehicle's indices are higher than those determined for Static Stability Overall Rating Index - System 1, as without loads, stability is increased.

The SSVs all have higher overall indices than the work Quad bikes, with points from 15.9 to 18.6, compared with 11.3 to 12.7 for the work Quad bikes.

The prototype Quad bike would have received 14.8 points with operator only and 14.1 with load. This would have placed this vehicle just below the lowest SSV but it would also have ranked as the most stable of all the Quad bikes, i.e. having the largest rollover resistance from all the Quad bikes. This demonstrates that it is possible to increase the rollover resistance of the Quad bikes.

Static Stability Overall Index- System 1 - all loads			Roll	Rear Pitch	Forward Pitch		
Type	Make	Model	Index Normalised	Index Normalised	Index Normalised	Total Index	**Weighted Total Index**
SSV	Honda	MUV700 big red	0.84	0.76	0.98	2.57	17.1
SSV	Tomcar	TM2	0.93	0.55	0.94	2.42	16.8
SSV	John Deere	XUV825i	0.80	0.77	0.93	2.50	16.5
SSV	Kubota	RTV500	0.76	0.64	0.97	2.36	15.6
SSV	Yamaha	Rhino	0.71	0.72	0.91	2.35	15.3
Quad	CF Moto	CF500	0.61	0.54	0.51	1.65	11.3
Quad	Polaris	Sportsman 450HO	0.60	0.47	0.54	1.62	11.1
Quad	Suzuki	Kingquad 400ASI	0.59	0.52	0.52	1.63	11.1
Quad	Honda	TRX500FM	0.60	0.51	0.51	1.62	11.1
Quad	Honda	TRX250	0.56	0.48	0.53	1.58	10.7
Quad	Yamaha	YFM450FAP Grizzly	0.53	0.54	0.49	1.57	10.5
Quad	Kawasaki	KVF300	0.56	0.49	0.49	1.53	10.5
Quad	Kymco	MXU300	0.49	0.48	0.48	1.45	9.7
							Max 20
Weighted Total Index =	5 x (2 x Roll + Rear Pitch + Forward Pitch)						

Table 13: Static Stability Overall Rating Index, System 1- with maximum loads, for the 8 production work Quad bikes and 5 production SSVs.

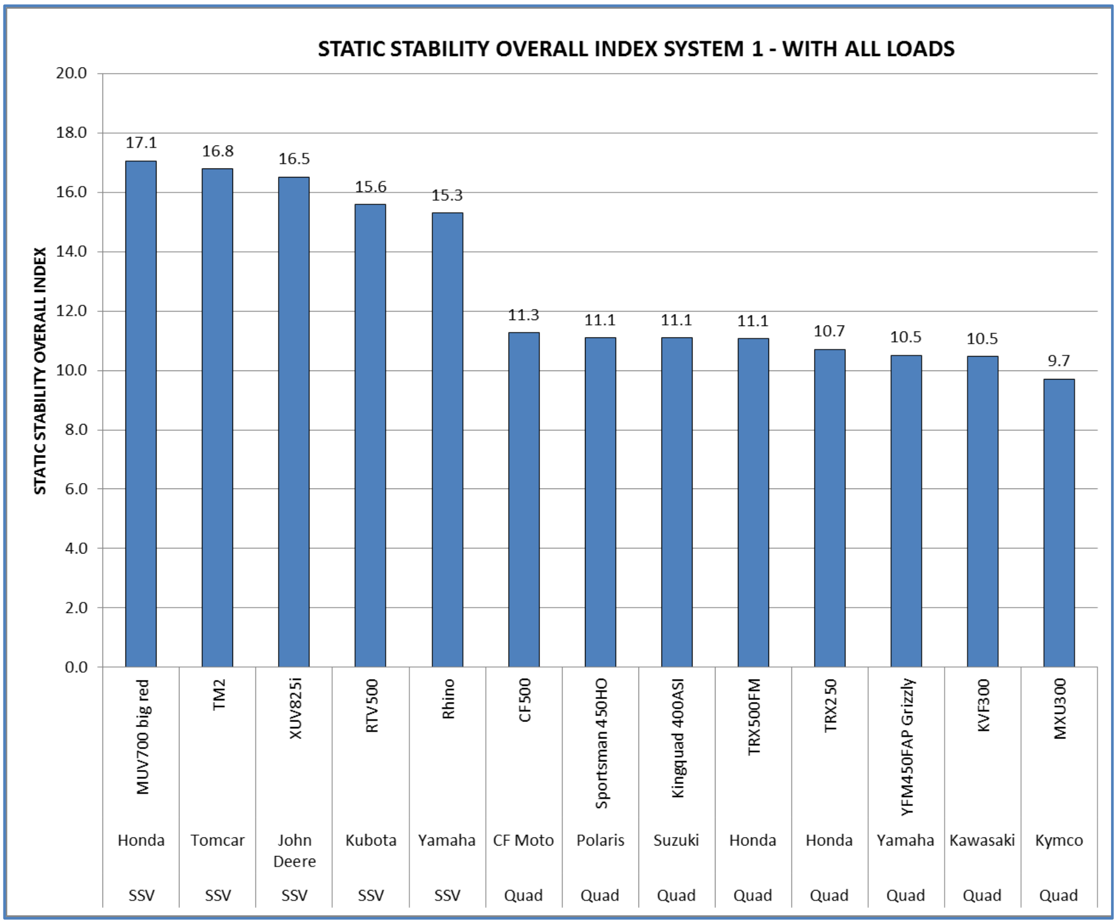

Figure 9: Bar chart showing the Static Stability Overall Rating Index, System 1- with maximum loads, for the 8 production work Quad bikes and 5 production SSVs.

Static Stability Overall Index System 2-no loads			Roll	Rear Pitch	Forward Pitch		
Type	Make	Model	Index Normalised	Index Normalised	Index Normalised	Total Index	**Weighted Total Index**
SSV	Honda	MUV700 big red	0.92	0.90	1.00	2.81	18.6
SSV	John Deere	XUV825i	0.88	0.88	0.91	2.68	17.8
SSV	Tomcar	TM2	0.98	0.60	0.96	2.55	17.7
SSV	Kubota	RTV500	0.80	0.71	1.00	2.51	16.6
SSV	Yamaha	Rhino	0.75	0.80	0.90	2.44	15.9
Quad	Can-am	DS90X	0.94	0.63	0.58	2.16	15.5
Quad	Honda	TRX700XX	0.79	0.56	0.62	1.98	13.9
Quad	Yamaha	YFM250R Raptor	0.75	0.59	0.57	1.91	13.3
Quad	Polaris	Sportsman 450HO	0.69	0.56	0.59	1.84	12.7
Quad	Suzuki	Kingquad 400ASI	0.67	0.61	0.56	1.85	12.6
Quad	Honda	TRX250	0.67	0.58	0.59	1.84	12.5
Quad	Honda	TRX500FM	0.67	0.61	0.54	1.83	12.5
Quad	CF Moto	CF500	0.67	0.61	0.53	1.81	12.4
Quad	Yamaha	YFM450FAP Grizzly	0.63	0.65	0.53	1.81	12.2
Quad	Kawasaki	KVF300	0.66	0.58	0.52	1.76	12.1
Quad	Kymco	MXU300	0.59	0.56	0.53	1.68	11.3
							Max 20
Weighted Total Index =		5 x (2 x Roll + Rear Pitch + Forward Pitch)					

Table 14: Static Stability Overall Rating Index, System 2 points - no loads, 16 production vehicles.

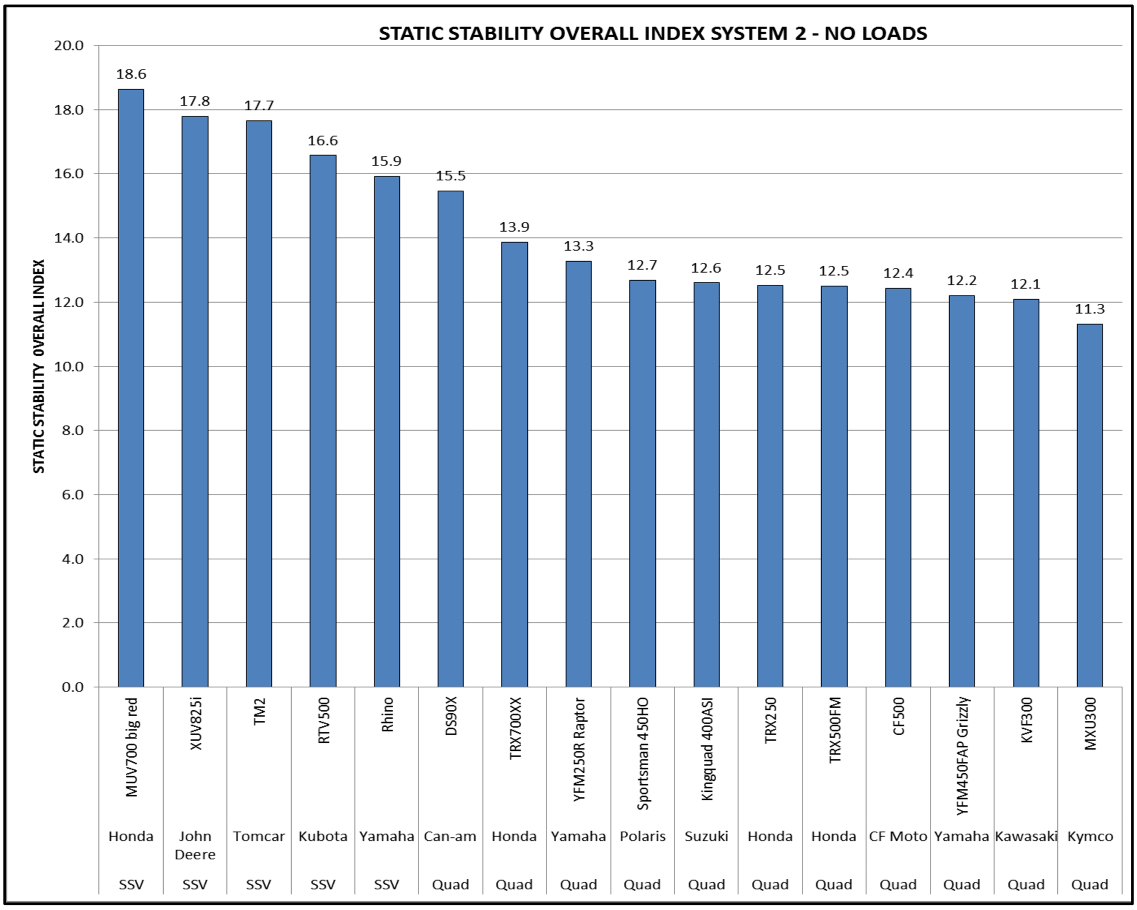

Figure 10: Static Stability Overall Rating Index, System 2 bar chart - no loads, for 16 production vehicles.

6 CONCLUSIONS FROM THE STATIC STABILITY TEST PROGRAM AND STATIC STABILITY OVERALL RATING INDICES

A comprehensive set of approximately 318 tests for the 16 production vehicles shown in Table 1 was carried out at the NSW Roads and Maritime Services Crashlab facility in Huntingwood, NSW, Australia. Detailed results for each of the 16 production vehicles in terms of maximum Tilt Table angles and Tilt Table Ratio (TTR) values for lateral roll, forward pitch and rear pitch were provided by Crashlab and are provided in Attachment 2. Highlights from those tests, interpretation of the test results, and how the Static Stability Overall Indices were computed are presented in this report. This report is presented as Part 1 of the three Part testing program, namely Part 1: Static Stability Test Results, Part 2: Dynamic Handling Test Results and Part 3: Rollover Crashworthiness Test Results.

6.1 Static Stability Test Results

Lateral rollover appears to be the predominant rollover direction for Quad bikes based on limited injury data available to date, and thus lateral stability is a relevant parameter for reduction of Quad bike rollover. Overall the work Quad bikes with rider and load, for a vehicle intended to be used on slopes and 'all-terrains', were observed to have a relatively low lateral stability with the Tilt Table Ratio (TTR) varying from 0.41 to 0.55 with a large rider and maximum manufacturer specified load. This suggests that such low lateral TTR values are likely to be, in many cases, incompatible with the working environment, e.g. steeper sloped terrains, in which such vehicles are being used on some types of farms, particularly for larger riders and full loads. That is, low lateral TTR values means these vehicles should be restricted for use on relatively low slopes and lower turning speeds for safe operation.

In comparison, SSVs have a higher lateral TTR than work Quad bikes, some by up to 40% to 60%. In either the fully loaded or unloaded condition, the least stable SSV is more stable (i.e. has a higher TTR) than the highest stability work Quad bike.

Regarding forward pitch stability, work Quad bikes have a higher TTR than they do for lateral stability. In forward pitch, SSVs have higher TTRs than work Quad bikes, some by up to double. The lowest stability SSV has a higher TTR than the highest stability work Quad bike, loaded or unloaded.

The rear pitch static stability for work Quad bikes is similar to the forward pitch stability. Rearward pitch stability is significantly higher than lateral stability. The SSVs have much lower rearward pitch stability than forward, up to 40% less. For the SSVs, rear pitch stability is about 20% higher than Quad bikes, with rider and rear maximum load. However the rear load capacity of SSVs is much greater than for Quad bikes.

For the OPDs, the Quadbar (8.6kg) has a minor and not significant effect on the static stability of the work Quad bikes. The Lifeguard (14.8kg) similarly has a small effect only on lateral and forward pitch stability, but with a greater effect on rear stability (approx. 10% reduction in TTR). The Quickfix unit being heavier (30kg) and higher, has a more pronounced effect on stability, reducing it, for example by about 11% laterally and 14% in forward pitch.

The Quickfix unit is not recommended for fitment as an OPD to any Quad bike because of its effect on reducing a Quad bike's TTR and also because it restricts a rider from standing upright on the vehicle and hence limits any Active Riding.

From a maximum slope and turning speed viewpoint in a workplace environment, particularly if large riders and full loads are also being carried, based on these test results, SSVs in general would be expected to be able to operate on steeper slopes than Quad bikes. They are also fitted with ROPS and seatbelts, unlike Quad bikes, and thus in the case of a rollover, may provide increased injury protection (in principle) than Quad bikes. The crashworthiness (injury protection) for both vehicle types is assessed in Part 3 of this study.

The measured Static Stability values, provide sufficient differentiation between models, loading conditions and vehicle types (i.e. Quad bikes vs SSVs), and the resulting Static Stability Overall Rating Index can be usefully applied to help assess 'Fit For Purpose' of the different available vehicles.

Regarding the sports/ recreational Quad bikes tested, these generally have higher TTRs in lateral roll than the work Quad bikes with rider. For these vehicles, Active Riding can play a part in increased stability albeit in a limited capacity. However, effectiveness is contingent on rider skill, age, weight relative to the Quad bike, etc., and to the Authors' knowledge its effectiveness has not been comprehensively evaluated.

The Authors have not been able to identify, including through the extensive Project Reference Group, any comprehensive study which has quantified the effectiveness of Active Riding as a reliable means to increase Quad bike stability, and to reduce rollover or loss of control/collision risk in a quantifiable way. As noted in the introduction, the effectiveness of Active Riding whether in the work environment or recreationally has not been quantified in published materials, to the Authors' knowledge. Based on the available information, the Authors therefore do not consider Active Riding to be a reliable rollover risk reduction strategy for Quad bikes in the work/ farm setting. The Authors suggest that a project be funded that properly examines and tests the effectiveness (particularly in the workplace/ farming environment) of the Active Riding style being promoted and taught at Quad bike training facilities.

These findings and observations from the Static Stability tests will be integrated with results from the Dynamic Handling tests, and the crashworthiness tests.

6.2 The Static Stability Overall Rating Index

Tables 13 and 14 and Figures 9 and 10 show the respective Static Stability Overall Rating Index - System 1 with all of the full load combinations and Static Stability Overall Rating Index - System 2 with rider and no loads. The SSVs have significantly higher indices than the work Quad bikes, with overall index values from 15.3 to 17.1, compared with 9.7 to 11.3 for the work Quad bikes for fully loaded vehicles, and for unloaded SSVs indices ranged from 15.9 to 18.6, compared with 11.3 to 12.7 for the work Quad bikes. The recreational Quad bike index values ranged from 13.3 to 15.5.

The vehicle with the highest overall index for vehicles not carrying any load, with one driver, was the Honda MUV700 Big Red. All SSVs had overall indices higher than 15.3. No work Quad bikes had overall indices greater than 12.7. The Kymco MXU300 Quad bike had the lowest index in both the fully loaded or unloaded configuration.

These overall indices indicated that if the Quad bikes tested were to be used to carry various loads such as hay bales, animals, liquids in tanks for spraying purposes or any loads, these could only operate on lower slope angles and at lower turning speeds in comparison to any of the SSVs tested.

Sand bags were used to apply the maximum loads recommended by the respective manufacturer and hence had a low profile as indicated in Attachment 2 in the Crashlab Report, Appendix E. The test results presented were not the worst case scenario for carrying loads. In many cases such as with spray tanks, these would have CoG heights higher than the test loading and therefore result in lower TTR values, i.e. even lower rollover resistance. Such lower TTR values would significantly reduce the slopes angles and turning speeds for which these Quad bikes loaded with a spray tank can be safely operated at.

In some instances riders have carried passengers on Quad bikes which have resulted in rollovers and serious injury. Tables 5 & 6 indicate a reduction of up to 40 % when a large rider sits on a Quad bike compared to the baseline Quad bike. While the Authors did not test a Quad bike with two people seated on the vehicle, it is clear that carrying a passenger would decrease TTR and thus reduce rollover resistance. Farmers and the general community should be encouraged through media and education programs to avoid carrying a pillion[24] and elevated loads on Quad bikes.

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7 References

1. Anon., An analysis of hazard and risk issues associated with recreational off-highway vehicles (ROVs), Heiden Associates, Alexandria Virginia, 27 January 2010.
2. Australian ATV Distributors, Australian ATV Distributors position paper. 2010, Australian ATV Distributors: Brisbane.
3. Carman A., Gillespie S., Jones K., Mackay J., Wallis G., and Milosavljevic S., All terrain vehicle loss of control events in agriculture: Contribution of pitch, roll and velocity. Ergonomics, 2010. 53(1): p. 18-29.
4. 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
5. Department of Infrastructure, Energy and Resources (DIER), SRT Calculator User Guide, TERNZ Ltd, Manukau, New Zealand, 25 May 2006.
6. Elder J., Leland E., (2006). CPSC Staff Response Regarding Follow-Up Questions from Commissioner Moore after the June 15, 2006, ATV Safety Review Briefing, in editor: http://www.cpsc.gov/LIBRARY/FOIA/FOIA06/brief/atvmoore.pdf
7. Franklin R.C., Stark K.L. and Fragar L.J., (2005). Evaluation of the New South Wales Rollover Protective Structure Rebate Scheme 2000 - 2004. Australian Centre for Agricultural Health and Safety (ACAHS), University of Sydney, Moree.
8. Garland S., 2011 annual report of ATV-related deaths and injuries, Directorate for Epidemiology, U.S. Consumer Product Safety Commission, Bethesda, Maryland, February 2013.
9. Garland S. and Streeter R., Review of reported injuries and fatalities associated with recreational off-highway vehicles (ROVs), Tab B of the Consumer Product Safety Commission Advanced Notice of Proposed Rulemaking Briefing Package, 25 September 2009.
10. Grzebieta R.H. and Achilles T., (2007). Report on Quad-bar in Relation to ATV Rollover Crashworthiness, submitted to Victorian Coroner Inquest into ATV deaths, Dept. Civil Engineering, Monash University, Victoria, Australia.
11. Grzebieta R.H., Rechnitzer G., McIntosh A, Mitchell R., Patton D., Simmons K. (2015a). Supplemental Report, Investigation and Analysis of Quad Bike and Side By Side (SSV) Fatalities and Injuries, Quad Bike Performance Project (QBPP), Transport and Road Safety (TARS) Research Report for The WorkCover Authority of New South Wales, University of New South Wales, Sydney, Australia.
12. Grzebieta R.H., Rechnitzer G., Simmons K. and McIntosh A.S. (2015b). Final Project Summary Report: Quad Bike Performance Project Test Results, Conclusions, and Recommendations, Report 4, Transport and Road Safety (TARS) Research Report for The WorkCover Authority of New South Wales, University of New South Wales, Sydney, Australia.

13. Helmkamp, J., Marsh, S., and Aikten, M., Occupational all-terrain vehicle deaths among workers 18 years and older in the United States, 1992-2007. Journal of Agricultural Safety and Health, 2011. 17(2): p. 147-155.

14. Lower T. (2013), "Quad Bikes –Time for Everyone to Take Action"; Media Release, July 2013, National Farm Safety Week Media Package 15-19 July 2013; FarmSafe Australia; and Australian Centre for Agricultural Health and Safety; University of Sydney. http://www.farmsafe.org.au/document.php?id=209

15. Lower T, Herde E & Fragar L (2012); Quad bike deaths in Australia 2001 to 2010; J Health Safety Environ 2012, 28(1): 7-24.

16. Mengert, P., Salvatore, S., DiSario, R., Walter, R., Statistical estimation of rollover risk, DOT-HS-807-466, U.S. Department of Transportation, August, 1989.

17. McIntosh A.S. and Patton D., (2014a). 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.

18. McIntosh A.S. and Patton D., (2014b). Report On United States Consumer Product Safety Commission (CPSC) Fatal ATV (Quad Bike) Crashes: Circumstances and Injury Patterns, Quad Bike Performance Project, Supplemental Report, Attachment 3, Transport and Road Safety (TARS) Research Report for The WorkCover Authority of New South Wales, University of New South Wales, Sydney, Australia.

19. 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.

20. Newstead, S. V. & Cameron, M. H. (1997) Correlation of results from New Car Assessment Program with real crash data, Monash University Accident Research Centre, Report No. 115

21. Olle J, (2009). Investigation into deaths of Vince Tobin, Joseph Jarvis Shepherd, Jye Kaden Jones, Peter Vaughn Crole, Thomas James Scutchings, John Neville Nash, Patricia Murray Simpson, Elijah Simpson with inquest, Melbourne: State Coroner Victoria, Australia.

22. National Highway Traffic Safety Administration (NHTSA), 49 CFR Part 575, [Docket No. NHTSA-2000-8298], Consumer Information Regulations; Federal Motor Vehicle Safety Standards; Rollover Resistance. http://www.nhtsa.gov/cars/rules/rulings/roll_resistance/

23. Perrone N, Simple Formula for Rollover Probability Based on DOT Accident Data, Accident Investigation Quarterly, pp20-12, Fall 1998.

24. Rechnitzer G, Day L, Grzebieta R, Zou R & Richardson S, (2003). All Terrain Vehicle Injuries and Deaths, Monash University Accident Research Centre.

25. Rechnitzer G, Grzebieta RH, McIntosh AS & Simmons K; Reducing All Terrain Vehicles (ATVs) Injuries And Deaths - A Way Ahead; Paper Number 13-0213; 23rd International

Technical Conference on the Enhanced Safety of Vehicles (ESV), Seoul, Korea, May 27-30, 2013.

26. Rechnitzer G, Richardson S, Hoareau E & Deveson N., Police Vehicles: rollover Stability Analysis (Phase 1 project); Monash University Accident Research Centre Report No. 184, March 2002.
27. Richier M, Lenain R, Thuilot B, and Debain C, On-line estimation of a stability metric including grip conditions and slope: Application to rollover prevention for All-Terrain Vehicles, 2011 IEEE/RSJ International Conference on Intelligent Robots and Systems September 25-30, 2011. San Francisco, CA, USA.
28. Richardson S, Grzebieta R & Rechnitzer G, A Methodology For Estimating Vehicle Rollover Propensity That Combines Stability Factor And Handling Metrics, 18th International Technical Conference on the Enhanced Safety of Vehicles, Nagoya, Japan, May 2003.
29. Richardson S, Rechnitzer G, Orton T, Shifman M & Crocker S, Development of Roll Over Protective Structures for Mining Light Vehicles, SAE World Congress and Exhibition April 2009, Detroit USA, SAE paper 2009-01-0831.
30. Roberts A, (2009). Dynamic Analysis of Side-by-Side Utility and Recreational Vehicles, Proc. 21st International Safety Conference on the Enhanced Safety of Vehicles, Stuttgart, Germany, June, Paper No.09-0260-O.Weir D.H & Zellner J.W., (1986), An introduction to the Operational Characteristics of All-terrain Vehicles, SAE paper 860225.
31. Shults, R.A., West, B.A., Rudd, R.A., and Helmkamp J.C., All-Terrain Vehicle–Related Nonfatal Injuries Among Young Riders in the United States, 2001–2010, Pediatrics, Volume 132, Number 2, August 2013.
32. Weir, D.H. and Zellner, J.W., An introduction to the operational characteristics of all-terrain vehicles, Society of Automotive Engineers Paper No. 860225, International Congress and Exposition, February 1986.
33. Young D, Grzebieta R H, Rechnitzer G, Bambach M and Richardson S, Rollover Crash safety: Characteristics and issues, Proceedings 5th Int. Crashworthiness Conf. ICRASH2006, Bolton Institute U.K., Athens, Greece, July 2006.

8 ATTACHMENT 1: Enlarged Results Spread Sheets and Charts for Lateral Roll, Rear Pitch and Forward Pitch, from Crashlab Test Data and Report (Attachment 2)

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4 Test Results

Table 2 – Test results roll

Angle at which each high side tyre (front and rear) lifts from the tilt table.

				No ATD						ATD					
Type	Make	Model	Specimen number	Front lift angle	tan theta	Rear lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Front lift angle	tan theta	Rear lift angle	tan theta	Greatest tilt angle	tan theta (TTR)
Quad	Honda	TRX250	TS57199	39.2	0.82	34.3	0.68	39.2	0.82	27.2	0.51	24.1	0.46	27.2	0.51
Quad	Honda	TRX500FM	TS57200	37.7	0.77	31.3	0.61	37.7	0.77	29.9	0.58	25.3	0.47	29.9	0.58
Quad	Yamaha	YFM450FAP Grizzly	TS57201	36.6	0.74	31.4	0.61	36.6	0.74	27.4	0.52	24.4	0.46	27.4	0.52
Quad	Polaris	Sportsman 450HO	TS57202	37.6	0.77	30.7	0.59	37.6	0.77	30.8	0.60	27.3	0.52	30.8	0.60
Quad	Suzuki	Kingquad 400ASI	TS57203	37.9	0.78	31.5	0.61	37.9	0.78	29.6	0.57	24.3	0.46	29.6	0.57
Quad	kawasaki	KVF300	TS57204	38.1	0.78	29.3	0.56	38.1	0.78	28.2	0.54	23.1	0.43	28.2	0.54
Quad	Kymco	MXU300	TS57205	35.7	0.72	29.1	0.56	35.7	0.72	24.5	0.46	21.8	0.40	24.5	0.46
Quad	CF Moto	CF500	TS57206	36.8	0.75	35.4	0.71	36.8	0.75	30.9	0.60	30.2	0.58	30.9	0.60
Quad	Can-am	DS90X	TS57211	47.6	1.10	36.2	0.73	47.6	1.10	37.9	0.78	31.3	0.61	37.9	0.78
Quad	Yamaha	YFM250R Raptor	TS57212	43.1	0.94	35.0	0.70	43.1	0.94	29.2	0.56	24.4	0.46	29.2	0.56
Quad	Honda	TRX700XX	TS57213	42.8	0.93	38.9	0.81	42.8	0.93	33.5	0.66	31.7	0.62	33.5	0.66
Quad	Honda	TRX250 + Quadbar	TS57199+CPD1	38.3	0.79	34.1	0.68	38.3	0.79	27.9	0.53	24.9	0.46	27.9	0.53
Quad	Honda	TRX250 + Lifeguard	TS57199+CPD2	35.9	0.72	31.6	0.62	35.9	0.72	26.4	0.50	24.2	0.46	26.4	0.50
Quad	Honda	TRX250 + Quickfix	TS57199+CPD3	31.4	0.61	24.4	0.45	31.4	0.61	24.0	0.45	20.9	0.38	24.0	0.45
Quad	Kymco	MXU300 + Quadbar	TS57205+CPD1	34.7	0.69	28.9	0.55	34.7	0.69	24.1	0.45	21.6	0.40	24.1	0.45
Quad	Kymco	MXU300 + Lifeguard	TS57205+CPD2	32.6	0.64	27.8	0.53	32.6	0.64	23.5	0.43	21.5	0.39	23.5	0.43
Quad	Kymco	MXU300 + Quickfix	TS57205+CPD3	28.0	0.53	22.9	0.42	28.0	0.53	20.5	0.37	18.4	0.33	20.5	0.37
Quad	CF Moto	CF500 + Quadbar	TS57206+CPD1	36.5	0.74	35.8	0.72	36.5	0.74	30.4	0.59	30.5	0.59	30.5	0.59
Quad	CF Moto	CF500 + Lifeguard	TS57206+CPD2	35.3	0.71	34.5	0.69	35.3	0.71	29.4	0.56	30.0	0.58	30.0	0.58
Quad	CF Moto	CF500 + Quickfix	TS57206+CPD3	33.0	0.65	31.4	0.61	33.0	0.65	28.6	0.55	27.7	0.53	28.6	0.55
SSV	Yamaha	YXR Rhino	TS57207	40.2	0.85	34.4	0.68	40.2	0.85	32.9	0.65	27.0	0.51	32.9	0.65
SSV	Kubota	RTV500	TS57208	41.7	0.89	37.7	0.77	41.7	0.89	35.7	0.72	32.4	0.63	35.7	0.72
SSV	John Deere	XUV825i	TS57209	40.7	0.86	43.3	0.94	43.3	0.94	37.2	0.76	39.4	0.82	39.4	0.82
SSV	Honda	MUV700 Big Red	TS57210	45.0	1.00	44.7	0.99	45.0	1.00	39.8	0.83	39.4	0.82	39.8	0.83
SSV	Tomcar	TM2	TS57620	45.3	1.01	40.8	0.86	45.3	1.01	43.8	0.96	39.8	0.83	43.8	0.96

				ATD + front load						ATD + front load + rear load						ATD + rear load					
Type	Make	Model	Specimen number	Front lift angle	tan theta	Rear lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Front lift angle	tan theta	Rear lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Front lift angle	tan theta	Rear lift angle	tan theta	Greatest tilt angle	tan theta (TTR)
Quad	Honda	TRX250	TS57199	26.1	0.49	21.9	0.40	26.1	0.49	26.0	0.49	23.4	0.43	26.0	0.49	27.2	0.51	25.6	0.48	27.2	0.51
Quad	Honda	TRX500FM	TS57200	29.6	0.57	22.2	0.41	29.6	0.57	27.2	0.51	24.2	0.45	27.2	0.51	29.1	0.56	27.2	0.51	29.1	0.56
Quad	Yamaha	YFM450FAP Grizzly	TS57201	24.5	0.46	19.9	0.36	24.5	0.46	23.5	0.43	22.2	0.41	23.5	0.43	27.3	0.52	27.1	0.51	27.3	0.52
Quad	Polaris	Sportsman 450HO	TS57202	28.2	0.54	24.4	0.45	28.2	0.54	27.8	0.53	26.4	0.50	27.8	0.53	28.9	0.55	29.4	0.56	29.4	0.56
Quad	Suzuki	Kingquad 400ASI	TS57203	27.9	0.53	22.6	0.42	27.9	0.53	27.6	0.52	24.2	0.45	27.6	0.52	29.2	0.56	26.1	0.49	29.2	0.56
Quad	kawasaki	KVF300	TS57204	25.9	0.49	20.4	0.37	25.9	0.49	25.0	0.47	21.7	0.40	25.0	0.47	27.2	0.51	24.0	0.45	27.2	0.51
Quad	Kymco	MXU300	TS57205	23.4	0.43	18.7	0.34	23.4	0.43	22.2	0.41	20.3	0.37	22.2	0.41	23.9	0.44	22.4	0.41	23.9	0.44
Quad	CF Moto	CF500	TS57206	29.5	0.57	27.4	0.52	29.5	0.57	28.5	0.54	29.0	0.55	29.0	0.55	27.8	0.53	29.2	0.56	29.2	0.56
Quad	Can-am	DS90X	TS57211																		
Quad	Yamaha	YFM250R Raptor	TS57212																		
Quad	Honda	TRX700XX	TS57213																		
Quad	Honda	TRX250 + Quadbar	TS57199+CPD1	25.9	0.49	22.0	0.40	25.9	0.49	25.6	0.48	23.6	0.44	25.6	0.48	27	0.51	25.7	0.48	27.0	0.51
Quad	Honda	TRX250 + Lifeguard	TS57199+CPD2	25.2	0.47	21.9	0.40	25.2	0.47	25.1	0.47	22.7	0.42	25.1	0.47	26.5	0.50	24.5	0.46	26.5	0.50
Quad	Honda	TRX250 + Quickfix	TS57199+CPD3	23.7	0.44	20.4	0.37	23.7	0.44	23.7	0.44	21.1	0.39	23.7	0.44	23.8	0.44	21.1	0.39	23.8	0.44
Quad	Kymco	MXU300 + Quadbar	TS57205+CPD1	22.7	0.42	18.9	0.34	22.7	0.42	22.0	0.40	20.1	0.37	22.0	0.40	24.3	0.45	22.5	0.41	24.3	0.45
Quad	Kymco	MXU300 + Lifeguard	TS57205+CPD2	22.0	0.40	19.0	0.34	22.0	0.40	21.5	0.39	19.5	0.35	21.5	0.39	23.8	0.44	22.0	0.40	23.8	0.44
Quad	Kymco	MXU300 + Quickfix	TS57205+CPD3	19.8	0.36	17.4	0.31	19.8	0.36	20.1	0.37	17.9	0.32	20.1	0.37	20.8	0.38	18.8	0.34	20.8	0.38
Quad	CF Moto	CF500 + Quadbar	TS57206+CPD1	30.5	0.59	28.3	0.54	30.5	0.59	27.7	0.53	28.8	0.55	28.8	0.55	26.5	0.50	28.9	0.55	28.9	0.55
Quad	CF Moto	CF500 + Lifeguard	TS57206+CPD2	28.7	0.55	27.4	0.52	28.7	0.55	28.7	0.55	29.0	0.55	29.0	0.55	27.4	0.52	29.0	0.55	29.0	0.55
Quad	CF Moto	CF500 + Quickfix	TS57206+CPD3	28.2	0.54	26.8	0.51	28.2	0.54	27.9	0.53	27.9	0.53	27.9	0.53	27.5	0.52	28.2	0.54	28.2	0.54
SSV	Yamaha	YXR Rhino	TS57207													32.8	0.64	31.7	0.62	32.8	0.64
SSV	Kubota	RTV500	TS57208													33.1	0.65	33.4	0.66	33.4	0.66
SSV	John Deere	XUV825i	TS57209													25.4	0.47	32.5	0.64	32.5	0.64
SSV	Honda	MUV700 Big Red	TS57210													29.8	0.57	34.3	0.68	34.3	0.68
SSV	Tomcar	TM2	TS57620													39.8	0.83	35.8	0.72	39.8	0.83

[grey box] = no load rack, not tested in this configuration.

Note: The point of rollover is the point at which both high side wheels (front and rear) have lifted from the table

Note: Tilt Table Ratio (TTR) is equal to the Tangent of the angle at which both high side wheels have left the table (point of rollover). See section 5.4 for more details

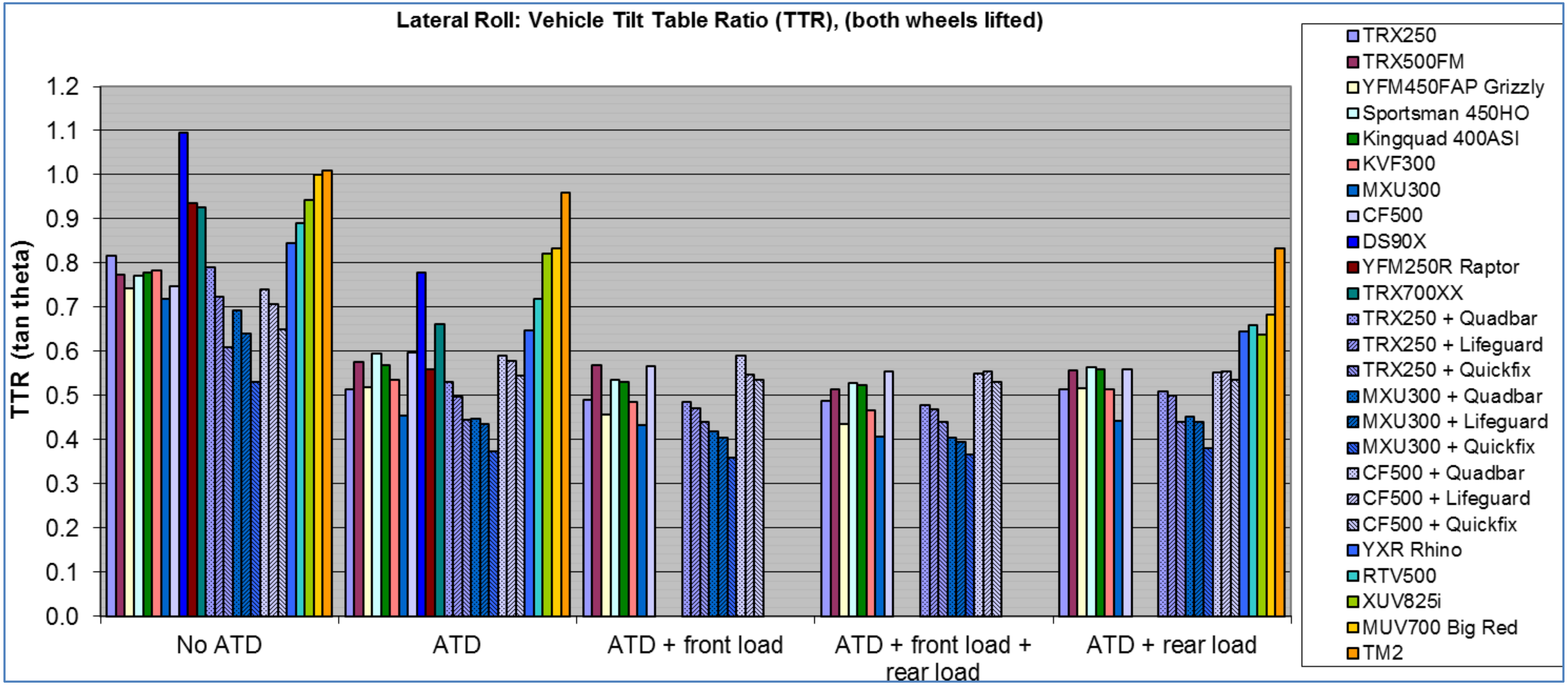

Lateral Roll: Vehicle Tilt Table Ratio (TTR), (both wheels lifted)
TTR (tan theta)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
No ATD
ATD
ATD + front load
ATD + front load + rear load
ATD + rear load
TRX250
TRX500FM
YFM450FAP Grizzly
Sportsman 450HO
Kingquad 400ASI
KVF300
MXU300
CF500
DS90X
YFM250R Raptor
TRX700XX
TRX250 + Quadbar
TRX250 + Lifeguard
TRX250 + Quickfix
MXU300 + Quadbar
MXU300 + Lifeguard
MXU300 + Quickfix
CF500 + Quadbar
CF500 + Lifeguard
CF500 + Quickfix
YXR Rhino
RTV500
XUV825i
MUV700 Big Red
TM2

Table 3 – Test results forward pitch

Angle at which each high side tyre (rear left and rear right) lifts from the tilt table.

				No ATD						ATD						ATD + front load						ATD + front load + rear load						ATD + rear load					
Type	Make	Model	Specimen number	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)
Quad	Honda	TRX250	TS57199	53.2	1.34	52.7	1.31	53.2	1.34	45.5	1.02	44.9	1.00	45.5	1.02	43.1	0.94	43.0	0.93	43.1	0.94	44.8	0.99	45.0	1.00	45.0	1.00	46.4	1.05	44.5	0.98	46.4	1.05
Quad	Honda	TRX500FM	TS57200	48.5	1.13	49.7	1.18	49.7	1.18	44.4	0.98	44.7	0.99	44.7	0.99	40.0	0.84	41.0	0.87	41.0	0.87	43.4	0.95	43.7	0.96	43.7	0.96	46.8	1.06	46.5	1.05	46.8	1.06
Quad	Yamaha	YFM450FAP Grizzly	TS57201	49.5	1.17	48.7	1.14	49.5	1.17	43.5	0.95	43.5	0.95	43.5	0.95	39.3	0.82	38.4	0.79	39.3	0.82	42.4	0.91	42.3	0.91	42.4	0.91	46.8	1.06	46.0	1.04	46.8	1.06
Quad	Polaris	Sportsman 450HO	TS57202	51.2	1.24	52.0	1.28	52.0	1.28	47.1	1.08	47.1	1.08	47.1	1.08	41.8	0.89	42.7	0.92	42.7	0.92	45.5	1.02	45.3	1.01	45.5	1.02	47.2	1.08	47.8	1.10	47.8	1.10
Quad	Suzuki	Kingquad 400ASI	TS57203	50.8	1.23	51.0	1.23	51.0	1.23	45.2	1.01	44.0	0.97	45.2	1.01	41.4	0.88	39.7	0.83	41.4	0.88	44.6	0.99	44.3	0.98	44.6	0.99	47.0	1.07	46.0	1.04	47.0	1.07
Quad	kawasaki	KVF300	TS57204	48.6	1.13	47.0	1.07	48.6	1.13	43.8	0.96	43.3	0.94	43.8	0.96	41.3	0.88	39.8	0.83	41.3	0.88	42.8	0.93	41.3	0.88	42.8	0.93	44.9	1.00	43.3	0.94	44.9	1.00
Quad	Kymco	MXU300	TS57205	49.4	1.17	47.5	1.09	49.4	1.17	43.2	0.94	41.6	0.89	43.2	0.94	40.3	0.85	38.0	0.78	40.3	0.85	41.6	0.89	39.5	0.82	41.6	0.89	44.0	0.97	42.4	0.91	44.0	0.97
Quad	CF Moto	CF500	TS57206	48.3	1.12	47.7	1.10	48.3	1.12	44.8	0.99	44.2	0.97	44.8	0.99	41.1	0.87	42.7	0.92	42.7	0.92	43.6	0.95	44.0	0.97	44.0	0.97	45.7	1.02	44.6	0.99	45.7	1.02
Quad	Can-am	DS90X	TS57211	51.3	1.25	52.7	1.31	52.7	1.31	45.5	1.02	45.7	1.02	45.7	1.02																		
Quad	Yamaha	YFM250R Raptor	TS57212	52.0	1.28	52.6	1.31	52.6	1.31	43.6	0.95	44.2	0.97	44.2	0.97																		
Quad	Honda	TRX700XX	TS57213	53.5	1.35	54.3	1.39	54.3	1.39	47.6	1.10	47.3	1.08	47.6	1.10																		
Quad	Honda	TRX250 + Quadbar	TS57199+CPD1	53.7	1.36	51.1	1.24	53.7	1.36	45.5	1.02	46.3	1.05	46.3	1.05	43.6	0.95	43.4	0.95	43.6	0.95	45.1	1.00	45.1	1.00	45.1	1.00	47.2	1.08	47.3	1.08	47.3	1.08
Quad	Honda	TRX250 + Lifeguard	TS57199+CPD2	49.6	1.17	51.8	1.27	51.8	1.27	45.1	1.00	44.9	1.00	45.1	1.00	43.1	0.94	42.5	0.92	43.1	0.94	43.9	0.96	43.5	0.95	43.9	0.96	46.0	1.04	45.4	1.01	46.0	1.04
Quad	Honda	TRX250 + Quickfix	TS57199+CPD3	44.9	1.00	45.5	1.02	45.5	1.02	41.5	0.88	40.7	0.86	41.5	0.88	41.3	0.88	40.9	0.87	41.3	0.88	42.1	0.90	41.5	0.88	42.1	0.90	42.2	0.91	41.5	0.88	42.2	0.91
Quad	Kymco	MXU300 + Quadbar	TS57205+CPD1	50.2	1.20	48.8	1.14	50.2	1.20	44.0	0.97	42.8	0.93	44.0	0.97	41.7	0.89	40.5	0.85	41.7	0.89	42.7	0.92	41.4	0.88	42.7	0.92	44.7	0.99	43.8	0.96	44.7	0.99
Quad	Kymco	MXU300 + Lifeguard	TS57205+CPD2	48.4	1.13	47.3	1.08	48.4	1.13	43.0	0.93	41.9	0.90	43.0	0.93	40.7	0.86	38.7	0.80	40.7	0.86	41.5	0.88	40.2	0.85	41.5	0.88	43.7	0.96	43.1	0.94	43.7	0.96
Quad	Kymco	MXU300 + Quickfix	TS57205+CPD3	42.8	0.93	41.9	0.90	42.8	0.93	39.7	0.83	37.5	0.77	39.7	0.83	38.8	0.80	37.0	0.75	38.8	0.80	39.3	0.82	37.3	0.76	39.3	0.82	40.1	0.84	38.1	0.78	40.1	0.84
Quad	CF Moto	CF500 + Quadbar	TS57206+CPD1	48.1	1.11	47.9	1.11	48.1	1.11	45.0	1.00	44.6	0.99	45.0	1.00	43.0	0.93	42.5	0.92	43.0	0.93	44.1	0.97	44.3	0.98	44.3	0.98	45.9	1.03	45.8	1.03	45.9	1.03
Quad	CF Moto	CF500 + Lifeguard	TS57206+CPD2	48.0	1.11	47.3	1.08	48.0	1.11	44.8	0.99	43.5	0.95	44.8	0.99	42.7	0.92	42.6	0.92	42.7	0.92	43.4	0.95	43.5	0.95	43.5	0.95	45.3	1.01	44.9	1.00	45.3	1.01
Quad	CF Moto	CF500 + Quickfix	TS57206+CPD3	44.6	0.99	44.3	0.98	44.6	0.99	42.5	0.92	41.5	0.88	42.5	0.92	42.1	0.90	41.1	0.87	42.1	0.90	42.8	0.93	42.0	0.90	42.8	0.93	43.2	0.94	42.3	0.91	43.2	0.94
SSV	Yamaha	YXR Rhino	TS57207	62.1	1.89	58.9	1.66	62.1	1.89	59.5	1.70	50.8	1.23	59.5	1.70													62.0	1.88	54.6	1.41	62.0	1.88
SSV	Kubota	RTV500	TS57208	65.2	2.16	65.4	2.18	65.4	2.18	60.7	1.78	61.0	1.80	61.0	1.80													61.1	1.81	56.6	1.52	61.1	1.81
SSV	John Deere	XUV825i	TS57209	61.9	1.87	62.1	1.89	62.1	1.89	60.2	1.75	58.2	1.61	60.2	1.75													61.6	1.85	62.8	1.95	62.8	1.95
SSV	Honda	MUV700 Big Red	TS57210	62.7	1.94	64.6	2.11	64.6	2.11	62.0	1.88	61.6	1.85	62.0	1.88													61.8	1.86	61.2	1.82	61.8	1.86
SSV	Tomcar	TM2	TS57620	62.5	1.92	63.2	1.98	63.2	1.98	58.0	1.60	61.6	1.85	61.6	1.85													58.1	1.61	61.2	1.82	61.2	1.82

(grey box) = no load rack, not tested in this configuration.

Note: The point of tipover is the point at which both high side wheels (rear) have lifted from the table

Note: Tilt Table Ratio (TTR) is equal to the Tangent of the angle at which both high side wheels have left the table (point of tipover)

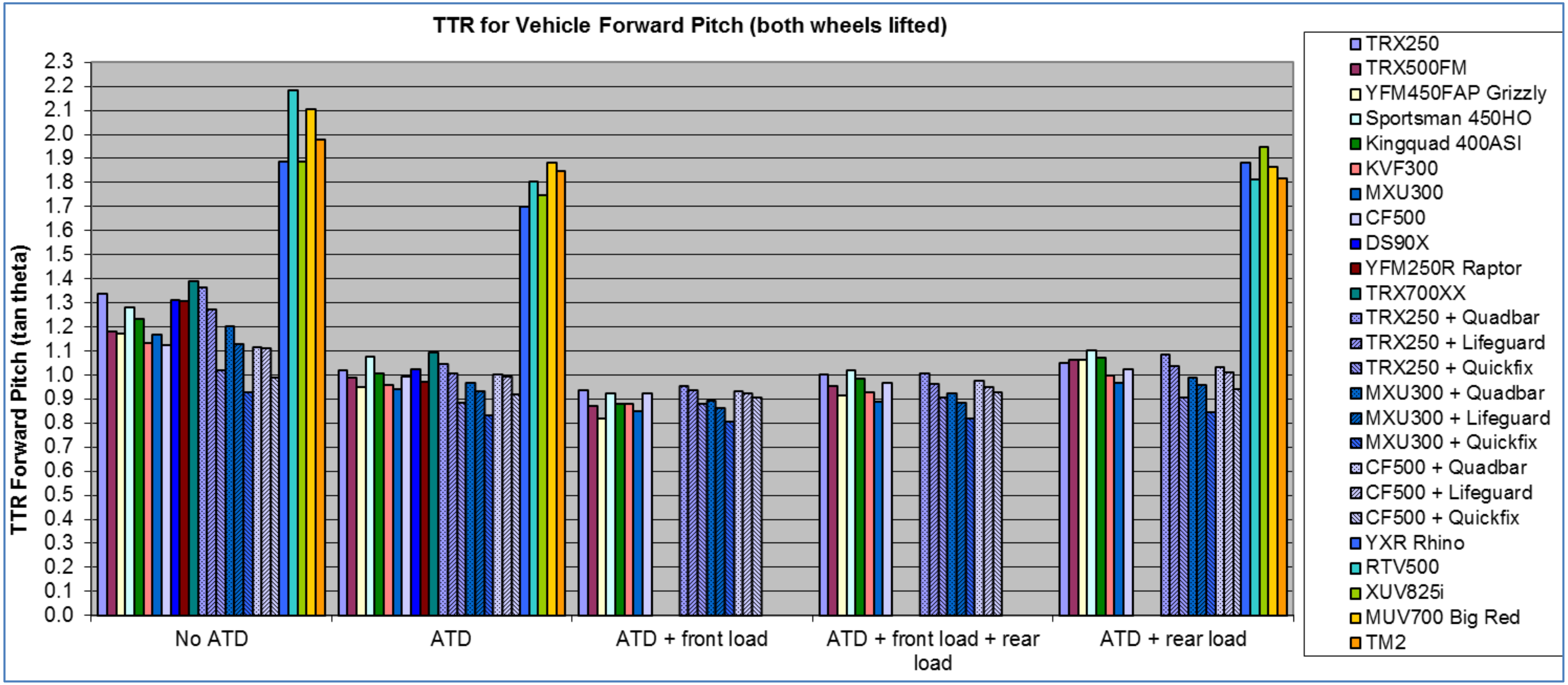

TTR for Vehicle Forward Pitch (both wheels lifted)
TTR Forward Pitch (tan theta)
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
No ATD
ATD
ATD + front load
ATD + front load + rear load
ATD + rear load
TRX250
TRX500FM
YFM450FAP Grizzly
Sportsman 450HO
Kingquad 400ASI
KVF300
MXU300
CF500
DS90X
YFM250R Raptor
TRX700XX
TRX250 + Quadbar
TRX250 + Lifeguard
TRX250 + Quickfix
MXU300 + Quadbar
MXU300 + Lifeguard
MXU300 + Quickfix
CF500 + Quadbar
CF500 + Lifeguard
CF500 + Quickfix
YXR Rhino
RTV500
XUV825i
MUV700 Big Red
TM2

Table 4 – Test results rearward pitch

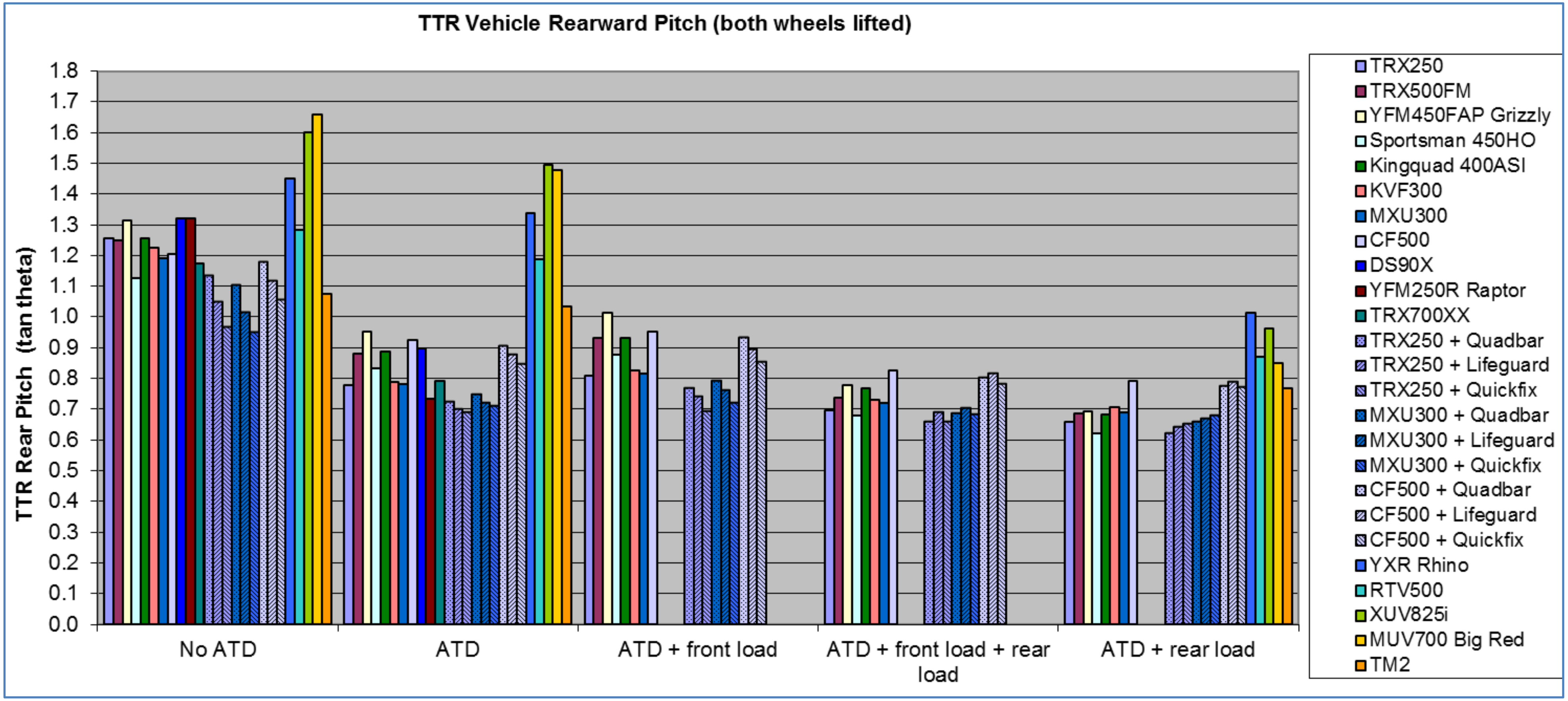
Angle at which each high side tyre (front left and front right) lifts from the tilt table.

				No ATD						ATD						ATD + front load						ATD + front load + rear load						ATD + rear load					
Type	Make	Model	Specimen number	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)
Quad	Honda	TRX250	TS57199	51.5	1.26	51.3	1.25	51.5	1.26	37.9	0.78	37.6	0.77	37.9	0.78	39.0	0.81	38.6	0.80	39.0	0.81	34.6	0.69	34.9	0.70	34.9	0.70	33.3	0.66	33.3	0.66	33.3	0.66
Quad	Honda	TRX500FM	TS57200	51.0	1.23	51.3	1.25	51.3	1.25	41.4	0.88	41.1	0.87	41.4	0.88	43.0	0.93	42.8	0.93	43.0	0.93	36.4	0.74	36.2	0.73	36.4	0.74	34.3	0.68	34.4	0.68	34.4	0.68
Quad	Yamaha	YFM450FAP Grizzly	TS57201	52.6	1.31	52.7	1.31	52.7	1.31	43.6	0.95	43.6	0.95	43.6	0.95	45.1	1.00	45.4	1.01	45.4	1.01	37.6	0.77	37.9	0.78	37.9	0.78	34.1	0.68	34.7	0.69	34.7	0.69
Quad	Polaris	Sportsman 450HO	TS57202	48.4	1.13	48.0	1.11	48.4	1.13	39.8	0.83	39.8	0.83	39.8	0.83	41.2	0.88	40.4	0.85	41.2	0.88	33.9	0.67	34.2	0.68	34.2	0.68	31.8	0.62	31.3	0.61	31.8	0.62
Quad	Suzuki	Kingquad 400ASI	TS57203	46.8	1.06	51.5	1.26	51.5	1.26	39.0	0.81	41.6	0.89	41.6	0.89	42.0	0.90	43.0	0.93	43.0	0.93	35.1	0.70	37.5	0.77	37.5	0.77	33.2	0.65	34.3	0.68	34.3	0.68
Quad	kawasaki	KVF300	TS57204	49.1	1.15	50.8	1.23	50.8	1.23	37.2	0.76	38.3	0.79	38.3	0.79	38.3	0.79	39.6	0.83	39.6	0.83	34.6	0.69	36.1	0.73	36.1	0.73	33.7	0.67	35.2	0.71	35.2	0.71
Quad	Kymco	MXU300	TS57205	48.0	1.11	50.0	1.19	50.0	1.19	36.6	0.74	38.0	0.78	38.0	0.78	37.9	0.78	39.2	0.82	39.2	0.82	34.4	0.68	35.7	0.72	35.7	0.72	32.7	0.64	34.6	0.69	34.6	0.69
Quad	CF Moto	CF500	TS57206	49.5	1.17	50.3	1.20	50.3	1.20	42.3	0.91	42.8	0.93	42.8	0.93	41.5	0.88	43.6	0.95	43.6	0.95	37.3	0.76	39.5	0.82	39.5	0.82	36.2	0.73	38.4	0.79	38.4	0.79
Quad	Can-am	DS90X	TS57211	52.6	1.31	52.9	1.32	52.9	1.32	41.7	0.89	41.9	0.90	41.9	0.90																		
Quad	Yamaha	YFM250R Raptor	TS57212	52.9	1.32	52.8	1.32	52.9	1.32	36.0	0.73	36.3	0.73	36.3	0.73																		
Quad	Honda	TRX700XX	TS57213	47.0	1.07	49.6	1.17	49.6	1.17	37.1	0.76	38.4	0.79	38.4	0.79																		
Quad	Honda	TRX250 + Quadbar	TS57199+CPD1	48.6	1.13	47.9	1.11	48.6	1.13	36.0	0.73	35.7	0.72	36.0	0.73	37.6	0.77	37.3	0.76	37.6	0.77	33.5	0.66	33.2	0.65	33.5	0.66	31.3	0.61	31.9	0.62	31.9	0.62
Quad	Honda	TRX250 + Lifeguard	TS57199+CPD2	46.4	1.05	45.4	1.01	46.4	1.05	35.0	0.70	35.0	0.70	35.0	0.70	36.6	0.74	36.4	0.74	36.6	0.74	34.6	0.69	34.3	0.68	34.6	0.69	32.8	0.64	32.8	0.64	32.8	0.64
Quad	Honda	TRX250 + Quickfix	TS57199+CPD3	44.1	0.97	42.9	0.93	44.1	0.97	34.7	0.69	34.7	0.69	34.7	0.69	34.8	0.70	34.5	0.69	34.8	0.70	33.2	0.65	33.4	0.66	33.4	0.66	33.1	0.65	32.7	0.64	33.1	0.65
Quad	Kymco	MXU300 + Quadbar	TS57205+CPD1	45.7	1.02	47.8	1.10	47.8	1.10	35.5	0.71	36.8	0.75	36.8	0.75	36.7	0.75	38.4	0.79	38.4	0.79	32.9	0.65	34.5	0.69	34.5	0.69	31.6	0.62	33.5	0.66	33.5	0.66
Quad	Kymco	MXU300 + Lifeguard	TS57205+CPD2	43.6	0.95	45.4	1.01	45.4	1.01	34.1	0.68	35.8	0.72	35.8	0.72	35.8	0.72	37.3	0.76	37.3	0.76	34.0	0.67	35.2	0.71	35.2	0.71	32.5	0.64	33.9	0.67	33.9	0.67
Quad	Kymco	MXU300 + Quickfix	TS57205+CPD3	40.9	0.87	43.5	0.95	43.5	0.95	34.0	0.67	35.4	0.71	35.4	0.71	34.4	0.68	35.8	0.72	35.8	0.72	33.0	0.65	34.4	0.68	34.4	0.68	32.9	0.65	34.2	0.68	34.2	0.68
Quad	CF Moto	CF500 + Quadbar	TS57206+CPD1	49.3	1.16	49.7	1.18	49.7	1.18	41.4	0.88	42.2	0.91	42.2	0.91	42.5	0.92	43.0	0.93	43.0	0.93	38.8	0.80	38.8	0.80	38.8	0.80	37.4	0.76	37.8	0.78	37.8	0.78
Quad	CF Moto	CF500 + Lifeguard	TS57206+CPD2	47.3	1.08	48.2	1.12	48.2	1.12	40.9	0.87	41.3	0.88	41.3	0.88	40.8	0.86	41.9	0.90	41.9	0.90	38.4	0.79	39.3	0.82	39.3	0.82	37.4	0.76	38.3	0.79	38.3	0.79
Quad	CF Moto	CF500 + Quickfix	TS57206+CPD3	46.0	1.04	46.6	1.06	46.6	1.06	39.5	0.82	40.3	0.85	40.3	0.85	40.1	0.84	40.5	0.85	40.5	0.85	37.7	0.77	38.1	0.78	38.1	0.78	37.0	0.75	37.7	0.77	37.7	0.77
SSV	Yamaha	YXR Rhino	TS57207	48.3	1.12	55.4	1.45	55.4	1.45	52.2	1.29	53.2	1.34	53.2	1.34													43.8	0.96	45.4	1.01	45.4	1.01
SSV	Kubota	RTV500	TS57208	52.1	1.28	46.1	1.04	52.1	1.28	49.9	1.19	44.5	0.98	49.9	1.19													41.0	0.87	36.8	0.75	41.0	0.87
SSV	John Deere	XUV825i	TS57209	58.0	1.60	55.0	1.43	58.0	1.60	56.2	1.49	50.5	1.21	56.2	1.49													43.9	0.96	38.4	0.79	43.9	0.96
SSV	Honda	MUV700 Big Red	TS57210	58.9	1.66	56.6	1.52	58.9	1.66	55.9	1.48	50.5	1.21	55.9	1.48													40.4	0.85	40.2	0.85	40.4	0.85
SSV	Tomcar	TM2	TS57620	42.3	0.91	47.1	1.08	47.1	1.08	42.3	0.91	46.0	1.04	46.0	1.04													34.1	0.68	37.5	0.77	37.5	0.77

[grey box] = no load rack, not tested in this configuration.

Note: The point of tipover is the point at which both high side wheels (front) have lifted from the table

Note: Tilt Table Ratio (TTR) is equal to the Tangent of the angle at which both high side wheels have left the table (point of tipover)


TTR Vehicle Rearward Pitch (both wheels lifted)
TTR Rear Pitch (tan theta)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
No ATD
ATD
ATD + front load
ATD + front load + rear load
ATD + rear load
TRX250
TRX500FM
YFM450FAP Grizzly
Sportsman 450HO
Kingquad 400ASI
KVF300
MXU300
CF500
DS90X
YFM250R Raptor
TRX700XX
TRX250 + Quadbar
TRX250 + Lifeguard
TRX250 + Quickfix
MXU300 + Quadbar
MXU300 + Lifeguard
MXU300 + Quickfix
CF500 + Quadbar
CF500 + Lifeguard
CF500 + Quickfix
YXR Rhino
RTV500
XUV825i
MUV700 Big Red
TM2

9 ATTACHMENT 2: Crashlab Static Stability Test Report

Crashlab Special Report SR2013/003, Quad Bike Performance Project: Quasi-static Tilt Testing, and Appendices A, B, C, D, E, F.

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

Our Ref: S/07141

Special Report SR2013/003

Quad bike performance project quasi-static tilt 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:	Purchase order: SCTEC-0000061638
Test Specification:	Work as directed by TARS, based upon Quad bike performance project – Tilt table quasi-static tilt test specification
Tests:	318 Tests
Date of Tests:	15th February 2013 to 2nd May 2013

Prepared by: ______________________ Date: 26JUN13

Drew Sherry, BE (Mech)
Test Engineer

Checked & Issued By: ______________________ Date: 26 JUN 13

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 the quasi-static rollover propensity of a number of commercially available quad bikes and side-by-side vehicles.

The test program was conducted using a single-axis tilt table to increase the lateral or longitudinal angle of the vehicle from horizontal to the angle of rollover or tip-over. The tilt table used for the testing was located at Crashlab, Huntingwood, NSW, Australia.

Load cells were positioned beneath each wheel of the vehicle and an inclinometer mounted to the tilting plane of the tilt table. The load cell and angle data of each tilt test was analysed to determine the angle of liftoff of each tyre and the quasi-static rollover angle of the vehicle.

The vehicles were tested in different load configurations which included;

- Unloaded
- With operator
- With operator and front cargo load
- With operator and rear cargo load
- With operator, front cargo load and rear cargo
- With Crush Protection Devices (CPDs).

The tests described in this report were conducted at the Crashlab facility between the 15th of February and the 2nd of May 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 which is fitted with handle bars for steering control.

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

Vehicle: Either a Quad bike or SSV

1.3 Program Objectives

The objectives of the Quad bike performance project tilt table test program were to:

- Determine the quasi-static lateral rollover angle of a number of commercially available Quad bikes and SSVs in a number of different operational load configurations
- Determine the quasi-static frontal longitudinal tip-over angle of a number of commercially available Quad bikes and SSVs in a number of different operational load configurations
- Determine the quasi-static rearwards longitudinal tip-over angle of a number of commercially available Quad bikes and SSVs in a number of different operational load configurations

2 Tilt table

In the test series the vehicles were tilted from the normal horizontal position through an arc of increasing angle until the point at which both tyres on the 'high-side' of the vehicle lost contact with the table and the vehicle rolled over. To achieve this motion a tilt table was used.

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

The table was fitted with four load cells which sit in the horizontal plane at the top surface of the table. The load cells are adjustable laterally and longitudinally so that they can be positioned under each wheel of vehicles with different track widths and wheelbases.

A digital angle sensor was fitted to the top frame of the table to measure the tilt angle of the surface.

Figure 1: Single axis tilt table with quad bike

3 Method

3.1 Test method

Sixteen vehicles were tested in this program. The test specification is located in Appendix A.

Each vehicle was positioned on the tilt table with each tyre in contact with a load cell. The table was raised about its tilt axis at a rate of less than one degree per second until the point at which both uphill or 'high side' tyres lost contact with their respective load cells. At this point the vehicle would tilt over and be caught by the two vehicle catch straps.

The angle at which each high side tyre lost contact with the ground (load cell) was recorded for each test configuration.

Testing was carried out with careful observation to ensure that the vehicle catch straps did not take the load of the vehicle before tipping over. The vehicle wheels were observed to ensure that they did not slip off the loads cells or contact the header board of the tilt table before the test was concluded.

3.2 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 D, vehicle photographs are contained in Appendix E.

3.3 Tilt axis

Each of the vehicles was tilted in three different directions.

- Lateral rollover, tilting about the longitudinal axis of the vehicle
- Frontal tip-over, tilting over the front axle of the vehicle
- Rear tip-over, tilting over the rear axle of the vehicle

3.4 Operator (ATD) load

Each vehicle was tested in each of the three tilt directions at the kerb mass (unoccupied with all fluid reservoirs filled to nominal capacity including fuel, and with all standard equipment) without any additional load to obtain a baseline vehicle measurement.

All vehicles that were rated for adult use were tested with a Hybrid III 95th percentile Anthropomorphic Test Device (ATD) seated in the operator position. The ATD weighed 101kg and 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 5th percentile Anthropomorphic Test Device (ATD) seated in the operator position. The ATD weighed 49kg and 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.

3.5 ATD Configuration & Positioning

The ATDs were positioned on the vehicle according to the procedure stated in Appendix A.

The quad bikes were fitted with non adjustable saddle seats with no occupant restraints.

For quad bikes the ATD was seated on the saddle with a vertical back angle, straight arms extended to handle bars with the hands on the grips and the ATD feet on the quad bike foot pegs.

The SSVs were fitted with bucket or bench seats with occupant restraints (seat belts). For SSVs the ATD was seated in the driver seat with its back against the backrest and the seat belt secured, the hands were located on the steering wheel.

The ATDs were secured to the vehicles with straps of mass of less than 1kg such that there was no relative movement of the ATD to the vehicle. This simulated the scenario of no counter-balance input from the operator.

3.6 Cargo load

A cargo load was applied to each vehicle in each of the nominated cargo areas. All tests conducted with cargo loads also had the operator (ATD) load in place.

- Vehicles fitted with front and rear load racks were tested with a front load only, a rear load only and both front and rear loads.
- Vehicles fitted with only a rear load tray were tested with a rear load only
- Vehicles not fitted with load racks were not tested with cargo loads

The load racks or load trays were loaded to their maximum manufacturer rated capacity. If the total mass of the ATD 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 for testing as compared to most real world load situations. The load was distributed evenly across the load area. The sand bags were restrained with webbing straps and sandwiched between thin ply boards to prevent the bags falling through the load rack and moving during the tests. The mass of the boards and straps were accounted for in the cargo load.

3.7 Crush Protection Devices (CPDs)

Three Crush Protection Devices (CPDs) were including in the test series to determine their effect on quad bike rollover propensity. Details of the three devices are included in Appendix G.

Each of the CPDs was fitted to three different quad bikes. The quad bikes were selected to represent a quad bike with typically high, median and low results with respect to rollover propensity.

The vehicles fitted with CPDs were then retested in all load configurations and tilt directions.

If the CPD applied a direct load to a cargo rack, the cargo load (sandbags) was reduced by the amount applied by the CPD so that the rated cargo rack capacity was not exceeded.

3.8 Test matrix

The test matrix consisted of 318 individual test configurations as tabled below

		No load			ATD			ATD+ front load			ATD+ front load+ rear load			ATD+ rear load		
Make	Model	Roll	Pitch Forward	Pitch rearward	Roll	Pitch Forward	Pitch rearward	Roll	Pitch Forward	Pitch rearward	Roll	Pitch Forward	Pitch rearward	Roll	Pitch Forward	Pitch rearward
Honda	TRX250	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Honda	TRX500FM	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Yamaha	YFM450FAP Grizzly	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Polaris	Sportsman 450HO	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Suzuki	Kingquad 400ASI	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
kawasaki	KVF300	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Kymco	MXU300	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CF Moto	CF500	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Yamaha	Rhino 700	1	1	1	1	1	1	*	*	*	*	*	*	1	1	1
Kubota	RTV500	1	1	1	1	1	1	*	*	*	*	*	*	1	1	1
John Deer	Gator XUV825i	1	1	1	1	1	1	*	*	*	*	*	*	1	1	1
Honda	Big red MUV700	1	1	1	1	1	1	*	*	*	*	*	*	1	1	1
Tomcar	TM2	1	1	1	1	1	1	*	*	*	*	*	*	1	1	1
Can-am	DS90X	1	1	1	1	1	1	*	*	*	*	*	*	*	*	*
Honda	TRX700XX	1	1	1	1	1	1	*	*	*	*	*	*	*	*	*
Yamaha	YFM250R Raptor	1	1	1	1	1	1	*	*	*	*	*	*	*	*	*
Quadbar CPD	Lowest roll ATV	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Highest roll ATV	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Median roll ATV	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Lifeguard CPD	Lowest roll ATV	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Highest roll ATV	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Median roll ATV	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Quickfix CPD	Lowest roll ATV	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Highest roll ATV	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Median roll ATV	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

* No load rack, not tested in this configuration

Roll total	106
Pitch forward total	106
Pitch rearward total	106
Total	**318**

Table 1- Test Matrix

For full test matrix with run numbers see Appendix B.

3.9 Instrumentation

To determine the lift-off point of each high side tyre during the test the tilt table was instrumented to measure load under each vehicle tyre and table angle, a total of five data channels.

The uni-axial load cells used are insensitive to eccentric loads and shear loads, only measuring the force normal to the load cell top surface. The base of load cells were secured within adjustable frames to allow for repositioning under tyres of vehicles with different wheel bases and track widths.

The load cells are rated to 700kg each and calibrated with an accuracy of greater than 0.2% and repeatability of greater than 0.4%.

The inclinometer was rigidly fixed to the upper frame of the tilt table with its measurement axis parallel to the tilt axis of the table.

The tilt sensor was calibrated with an accuracy of greater than 0.2%.

The load traces of each high-side load cell were used to determine the point of separation of the vehicle tyre from the load cell. This was determined as the point at which the load on the instrument reached zero, which is characterised by a noticeable point of inflection in the load-angle data trace. The load cell data was post-processed such that the self mass of the load cell was eliminated for the given angle of measurement.

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

3.10 Data acquisition

Crashlab's DTS Slice (Data Acquisition Unit) and Diadem software were used for data acquisition and analysis. Signal conditioning, including amplification was provided close to the instrumentation. The data was recorded at an acquisition rate of 100 Hz per channel.

3.11 Test repeatability

During tilt table commissioning roll tests were carried out on a single vehicle in a single load configuration. Three tests were carried out with the vehicle located in the same position on the load cells. The angle of lift for the rear tyre (first to lift) varied by no more than 0.5 degrees. The angle of lift for the front tyre (second to lift, vehicle rollover achieved) varied by no more than 0.1 degrees.

The vehicle was tested a further three times with the tyres in different locations on the load cells. The point of lift for the rear tyre (first to lift) varied from the average of the first three tests by no more than 0.4 degrees. The point of lift for the front tyre (second to lift, vehicle rollover achieved) varied from the average of the first three tests by no more than 0.4 degrees.

The first vehicle tested in the roll configuration was tested at all five load conditions twice. Between tests of the same load condition the angle at rear wheel lift varied by an average of 0.4 degrees (with a maximum variance of 0.8 degrees). The angle at front wheel lift (angle at rollover) varied by an average of 0.4 degrees (with a maximum variance of 0.5 degrees).

With typical roll angles in the range of 20° to 45° this represents a repeatability range of 2% to 4%

4 Test Results

Table 2 – Test results roll

Angle at which each high side tyre (front and rear) lifts from the tilt table.

				No ATD						ATD						ATD + front load						ATD + front load + rear load						ATD + rear load					
Type	Make	Model	Specimen number	Front lift angle	tan theta	Rear lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Front lift angle	tan theta	Rear lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Front lift angle	tan theta	Rear lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Front lift angle	tan theta	Rear lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Front lift angle	tan theta	Rear lift angle	tan theta	Greatest tilt angle	tan theta (TTR)
Quad	Honda	TRX250	TS57199	39.2	0.82	34.3	0.68	39.2	0.82	27.2	0.51	24.1	0.45	27.2	0.51	26.1	0.49	21.9	0.40	26.1	0.49	26.0	0.49	23.4	0.43	26.0	0.49	27.2	0.51	25.6	0.48	27.2	0.51
Quad	Honda	TRX500FM	TS57200	37.7	0.77	31.3	0.61	37.7	0.77	29.9	0.58	25.3	0.47	29.9	0.58	29.6	0.57	22.2	0.41	29.6	0.57	27.2	0.51	24.2	0.45	27.2	0.51	29.1	0.56	27.2	0.51	29.1	0.56
Quad	Yamaha	YFM450FAP Grizzly	TS57201	36.6	0.74	31.4	0.61	36.6	0.74	27.4	0.52	24.4	0.45	27.4	0.52	24.5	0.46	19.9	0.36	24.5	0.46	23.5	0.43	22.2	0.41	23.5	0.43	27.3	0.52	27.1	0.51	27.3	0.52
Quad	Polaris	Sportsman 450HO	TS57202	37.6	0.77	30.7	0.59	37.6	0.77	30.8	0.60	27.3	0.52	30.8	0.60	28.2	0.54	24.4	0.45	28.2	0.54	27.8	0.53	26.4	0.50	27.8	0.53	28.9	0.55	29.4	0.56	29.4	0.56
Quad	Suzuki	Kingquad 400ASI	TS57203	37.9	0.78	31.5	0.61	37.9	0.78	29.6	0.57	24.3	0.45	29.6	0.57	27.9	0.53	22.6	0.42	27.9	0.53	27.6	0.52	24.2	0.45	27.6	0.52	29.2	0.56	26.1	0.49	29.2	0.56
Quad	kawasaki	KVF300	TS57204	38.1	0.78	29.3	0.56	38.1	0.78	28.2	0.54	23.1	0.43	28.2	0.54	25.9	0.49	20.4	0.37	25.9	0.49	25.0	0.47	21.7	0.40	25.0	0.47	27.2	0.51	24.0	0.45	27.2	0.51
Quad	Kymco	MXU300	TS57205	35.7	0.72	29.1	0.56	35.7	0.72	24.5	0.46	21.8	0.40	24.5	0.46	23.4	0.43	18.7	0.34	23.4	0.43	22.2	0.41	20.3	0.37	22.2	0.41	23.9	0.44	22.4	0.41	23.9	0.44
Quad	CF Moto	CF500	TS57206	36.8	0.75	35.4	0.71	36.8	0.75	30.9	0.60	30.2	0.58	30.9	0.60	29.5	0.57	27.4	0.52	29.5	0.57	28.5	0.54	29.0	0.55	29.0	0.55	27.8	0.53	29.2	0.56	29.2	0.56
Quad	Can-am	DS90X	TS57211	47.6	1.10	36.2	0.73	47.6	1.10	37.9	0.78	31.3	0.61	37.9	0.78																		
Quad	Yamaha	YFM250R Raptor	TS57212	43.1	0.94	35.0	0.70	43.1	0.94	29.2	0.56	24.4	0.45	29.2	0.56																		
Quad	Honda	TRX700XX	TS57213	42.8	0.93	38.9	0.81	42.8	0.93	33.5	0.66	31.7	0.62	33.5	0.66																		
Quad	Honda	TRX250 + Quadbar	TS57199+CPD1	38.3	0.79	34.1	0.68	38.3	0.79	27.9	0.53	24.9	0.46	27.9	0.53	25.9	0.49	22.0	0.40	25.9	0.49	25.6	0.48	23.6	0.44	25.6	0.48	27	0.51	25.7	0.48	27.0	0.51
Quad	Honda	TRX250 + Lifeguard	TS57199+CPD2	35.9	0.72	31.6	0.62	35.9	0.72	26.4	0.50	24.2	0.45	26.4	0.50	25.2	0.47	21.9	0.40	25.2	0.47	25.1	0.47	22.7	0.42	25.1	0.47	26.5	0.50	24.5	0.46	26.5	0.50
Quad	Honda	TRX250 + Quickfix	TS57199+CPD3	31.4	0.61	24.4	0.45	31.4	0.61	24.0	0.45	20.9	0.38	24.0	0.45	23.7	0.44	20.4	0.37	23.7	0.44	23.7	0.44	21.1	0.39	23.7	0.44	23.8	0.44	21.1	0.39	23.8	0.44
Quad	Kymco	MXU300 + Quadbar	TS57205+CPD1	34.7	0.69	28.9	0.55	34.7	0.69	24.1	0.45	21.6	0.40	24.1	0.45	22.7	0.42	18.9	0.34	22.7	0.42	22.0	0.40	20.1	0.37	22.0	0.40	24.3	0.45	22.5	0.41	24.3	0.45
Quad	Kymco	MXU300 + Lifeguard	TS57205+CPD2	32.6	0.64	27.8	0.53	32.6	0.64	23.5	0.43	21.5	0.39	23.5	0.43	22.0	0.40	19.0	0.34	22.0	0.40	21.5	0.39	19.5	0.35	21.5	0.39	23.8	0.44	22.0	0.40	23.8	0.44
Quad	Kymco	MXU300 + Quickfix	TS57205+CPD3	28.0	0.53	22.9	0.42	28.0	0.53	20.5	0.37	18.4	0.33	20.5	0.37	19.8	0.36	17.4	0.31	19.8	0.36	20.1	0.37	17.9	0.32	20.1	0.37	20.8	0.38	18.8	0.34	20.8	0.38
Quad	CF Moto	CF500 + Quadbar	TS57206+CPD1	36.5	0.74	35.8	0.72	36.5	0.74	30.4	0.59	30.5	0.59	30.5	0.59	30.5	0.59	28.3	0.54	30.5	0.59	27.7	0.53	28.8	0.55	28.8	0.55	26.5	0.50	28.9	0.55	28.9	0.55
Quad	CF Moto	CF500 + Lifeguard	TS57206+CPD2	35.3	0.71	34.5	0.69	35.3	0.71	29.4	0.56	30.0	0.58	30.0	0.58	28.7	0.55	27.4	0.52	28.7	0.55	28.7	0.55	29.0	0.55	29.0	0.55	27.4	0.52	29.0	0.55	29.0	0.55
Quad	CF Moto	CF500 + Quickfix	TS57206+CPD3	33.0	0.65	31.4	0.61	33.0	0.65	28.6	0.55	27.7	0.53	28.6	0.55	28.2	0.54	26.8	0.51	28.2	0.54	27.9	0.53	27.9	0.53	27.9	0.53	27.5	0.52	28.2	0.54	28.2	0.54
SSV	Yamaha	YXR Rhino	TS57207	40.2	0.85	34.4	0.68	40.2	0.85	32.9	0.65	27.0	0.51	32.9	0.65													32.8	0.64	31.7	0.62	32.8	0.64
SSV	Kubota	RTV500	TS57208	41.7	0.89	37.7	0.77	41.7	0.89	35.7	0.72	32.4	0.63	35.7	0.72													33.1	0.65	33.4	0.66	33.4	0.66
SSV	John Deere	XUV825i	TS57209	40.7	0.86	43.3	0.94	43.3	0.94	37.2	0.76	39.4	0.82	39.4	0.82													25.4	0.47	32.5	0.64	32.5	0.64
SSV	Honda	MUV700 Big Red	TS57210	45.0	1.00	44.7	0.99	45.0	1.00	39.8	0.83	39.4	0.82	39.8	0.83													29.8	0.57	34.3	0.68	34.3	0.68
SSV	Tomcar	TM2	TS57620	45.3	1.01	40.8	0.86	45.3	1.01	43.8	0.96	39.8	0.83	43.8	0.96													39.8	0.83	35.8	0.72	39.8	0.83

[grey box] = no load rack, not tested in this configuration.

Note: The point of rollover is the point at which both high side wheels (front and rear) have lifted from the table

Note: Tilt Table Ratio (TTR) is equal to the Tangent of the angle at which both high side wheels have left the table (point of rollover). See section 5.4 for more details

Data traces of load-angle for the high side wheels for each test are located in Appendix C of this report.

Table 3 – Test results forward pitch

Angle at which each high side tyre (rear left and rear right) lifts from the tilt table.

				No ATD						ATD						ATD + front load						ATD + front load + rear load						ATD + rear load					
Type	Make	Model	Specimen number	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)
Quad	Honda	TRX250	TS57199	53.2	1.34	52.7	1.31	53.2	1.34	45.5	1.02	44.9	1.00	45.5	1.02	43.1	0.94	43.0	0.93	43.1	0.94	44.8	0.99	45.0	1.00	45.0	1.00	46.4	1.05	44.5	0.98	46.4	1.05
Quad	Honda	TRX500FM	TS57200	48.5	1.13	49.7	1.18	49.7	1.18	44.4	0.98	44.7	0.99	44.7	0.99	40.0	0.84	41.0	0.87	41.0	0.87	43.4	0.95	43.7	0.96	43.7	0.96	46.8	1.06	46.5	1.05	46.8	1.06
Quad	Yamaha	YFM450FAP Grizzly	TS57201	49.5	1.17	48.7	1.14	49.5	1.17	43.5	0.95	43.5	0.95	43.5	0.95	39.3	0.82	38.4	0.79	39.3	0.82	42.4	0.91	42.3	0.91	42.4	0.91	46.8	1.06	46.0	1.04	46.8	1.06
Quad	Polaris	Sportsman 450HO	TS57202	51.2	1.24	52.0	1.28	52.0	1.28	47.1	1.08	47.1	1.08	47.1	1.08	41.8	0.89	42.7	0.92	42.7	0.92	45.5	1.02	45.3	1.01	45.5	1.02	47.2	1.08	47.8	1.10	47.8	1.10
Quad	Suzuki	Kingquad 400ASI	TS57203	50.8	1.23	51.0	1.23	51.0	1.23	45.2	1.01	44.0	0.97	45.2	1.01	41.4	0.88	39.7	0.83	41.4	0.88	44.6	0.99	44.3	0.98	44.6	0.99	47.0	1.07	46.0	1.04	47.0	1.07
Quad	kawasaki	KVF300	TS57204	48.6	1.13	47.0	1.07	48.6	1.13	43.8	0.96	43.3	0.94	43.8	0.96	41.3	0.88	39.8	0.83	41.3	0.88	42.8	0.93	41.3	0.88	42.8	0.93	44.9	1.00	43.3	0.94	44.9	1.00
Quad	Kymco	MXU300	TS57205	49.4	1.17	47.5	1.09	49.4	1.17	43.2	0.94	41.6	0.89	43.2	0.94	40.3	0.85	38.0	0.78	40.3	0.85	41.6	0.89	39.5	0.82	41.6	0.89	44.0	0.97	42.4	0.91	44.0	0.97
Quad	CF Moto	CF500	TS57206	48.3	1.12	47.7	1.10	48.3	1.12	44.8	0.99	44.2	0.97	44.8	0.99	41.1	0.87	42.7	0.92	42.7	0.92	43.6	0.95	44.0	0.97	44.0	0.97	45.7	1.02	44.6	0.99	45.7	1.02
Quad	Can-am	DS90X	TS57211	51.3	1.25	52.7	1.31	52.7	1.31	45.5	1.02	45.7	1.02	45.7	1.02																		
Quad	Yamaha	YFM250R Raptor	TS57212	52.0	1.28	52.6	1.31	52.6	1.31	43.6	0.95	44.2	0.97	44.2	0.97																		
Quad	Honda	TRX700XX	TS57213	53.5	1.35	54.3	1.39	54.3	1.39	47.6	1.10	47.3	1.08	47.6	1.10																		
Quad	Honda	TRX250 + Quadbar	TS57199+CPD1	53.7	1.36	51.1	1.24	53.7	1.36	45.5	1.02	46.3	1.05	46.3	1.05	43.6	0.95	43.4	0.95	43.6	0.95	45.1	1.00	45.1	1.00	45.1	1.00	47.2	1.08	47.3	1.08	47.3	1.08
Quad	Honda	TRX250 + Lifeguard	TS57199+CPD2	49.6	1.17	51.8	1.27	51.8	1.27	45.1	1.00	44.9	1.00	45.1	1.00	43.1	0.94	42.5	0.92	43.1	0.94	43.9	0.96	43.5	0.95	43.9	0.96	46.0	1.04	45.4	1.01	46.0	1.04
Quad	Honda	TRX250 + Quickfix	TS57199+CPD3	44.9	1.00	45.5	1.02	45.5	1.02	41.5	0.88	40.7	0.86	41.5	0.88	41.3	0.88	40.9	0.87	41.3	0.88	42.1	0.90	41.5	0.88	42.1	0.90	42.2	0.91	41.5	0.88	42.2	0.91
Quad	Kymco	MXU300 + Quadbar	TS57205+CPD1	50.2	1.20	48.8	1.14	50.2	1.20	44.0	0.97	42.8	0.93	44.0	0.97	41.7	0.89	40.5	0.85	41.7	0.89	42.7	0.92	41.4	0.88	42.7	0.92	44.7	0.99	43.8	0.96	44.7	0.99
Quad	Kymco	MXU300 + Lifeguard	TS57205+CPD2	48.4	1.13	47.3	1.08	48.4	1.13	43.0	0.93	41.9	0.90	43.0	0.93	40.7	0.86	38.7	0.80	40.7	0.86	41.5	0.88	40.2	0.85	41.5	0.88	43.7	0.96	43.1	0.94	43.7	0.96
Quad	Kymco	MXU300 + Quickfix	TS57205+CPD3	42.8	0.93	41.9	0.90	42.8	0.93	39.7	0.83	37.5	0.77	39.7	0.83	38.8	0.80	37.0	0.75	38.8	0.80	39.3	0.82	37.3	0.76	39.3	0.82	40.1	0.84	38.1	0.78	40.1	0.84
Quad	CF Moto	CF500 + Quadbar	TS57206+CPD1	48.1	1.11	47.9	1.11	48.1	1.11	45.0	1.00	44.6	0.99	45.0	1.00	43.0	0.93	42.5	0.92	43.0	0.93	44.1	0.97	44.3	0.98	44.3	0.98	45.9	1.03	45.8	1.03	45.9	1.03
Quad	CF Moto	CF500 + Lifeguard	TS57206+CPD2	48.0	1.11	47.3	1.08	48.0	1.11	44.8	0.99	43.5	0.95	44.8	0.99	42.7	0.92	42.6	0.92	42.7	0.92	43.4	0.95	43.5	0.95	43.5	0.95	45.3	1.01	44.9	1.00	45.3	1.01
Quad	CF Moto	CF500 + Quickfix	TS57206+CPD3	44.6	0.99	44.3	0.98	44.6	0.99	42.5	0.92	41.5	0.88	42.5	0.92	42.1	0.90	41.1	0.87	42.1	0.90	42.8	0.93	42.0	0.90	42.8	0.93	43.2	0.94	42.3	0.91	43.2	0.94
SSV	Yamaha	YXR Rhino	TS57207	62.1	1.89	58.9	1.66	62.1	1.89	59.5	1.70	50.8	1.23	59.5	1.70													62.0	1.88	54.6	1.41	62.0	1.88
SSV	Kubota	RTV500	TS57208	65.2	2.16	65.4	2.18	65.4	2.18	60.7	1.78	61.0	1.80	61.0	1.80													61.1	1.81	56.6	1.52	61.1	1.81
SSV	John Deere	XUV825i	TS57209	61.9	1.87	62.1	1.89	62.1	1.89	60.2	1.75	58.2	1.61	60.2	1.75													61.6	1.85	62.8	1.95	62.8	1.95
SSV	Honda	MUV700 Big Red	TS57210	62.7	1.94	64.6	2.11	64.6	2.11	62.0	1.88	61.6	1.85	62.0	1.88													61.8	1.86	61.2	1.82	61.8	1.86
SSV	Tomcar	TM2	TS57620	62.5	1.92	63.2	1.98	63.2	1.98	58.0	1.60	61.6	1.85	61.6	1.85													58.1	1.61	61.2	1.82	61.2	1.82

[grey box] = no load rack, not tested in this configuration.

Note: The point of tipover is the point at which both high side wheels (rear) have lifted from the table

Note: Tilt Table Ratio (TTR) is equal to the Tangent of the angle at which both high side wheels have left the table (point of tipover)

Data traces of load-angle for the high side wheels for each test are located in Appendix C of this report.

Table 4 – Test results rearward pitch

Angle at which each high side tyre (front left and front right) lifts from the tilt table.

				No ATD						ATD						ATD + front load						ATD + front load + rear load						ATD + rear load					
Type	Make	Model	Specimen number	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)	Left lift angle	tan theta	Right lift angle	tan theta	Greatest tilt angle	tan theta (TTR)
Quad	Honda	TRX250	TS57199	51.5	1.26	51.3	1.25	51.5	1.26	37.9	0.78	37.6	0.77	37.9	0.78	39.0	0.81	38.6	0.80	39.0	0.81	34.6	0.69	34.9	0.70	34.9	0.70	33.3	0.66	33.3	0.66	33.3	0.66
Quad	Honda	TRX500FM	TS57200	51.0	1.23	51.3	1.25	51.3	1.25	41.4	0.88	41.1	0.87	41.4	0.88	43.0	0.93	42.8	0.93	43.0	0.93	36.4	0.74	36.2	0.73	36.4	0.74	34.3	0.68	34.4	0.68	34.4	0.68
Quad	Yamaha	YFM450FAP Grizzly	TS57201	52.6	1.31	52.7	1.31	52.7	1.31	43.6	0.95	43.6	0.95	43.6	0.95	45.1	1.00	45.4	1.01	45.4	1.01	37.6	0.77	37.9	0.78	37.9	0.78	34.1	0.68	34.7	0.69	34.7	0.69
Quad	Polaris	Sportsman 450HO	TS57202	48.4	1.13	48.0	1.11	48.4	1.13	39.8	0.83	39.8	0.83	39.8	0.83	41.2	0.88	40.4	0.85	41.2	0.88	33.9	0.67	34.2	0.68	34.2	0.68	31.8	0.62	31.3	0.61	31.8	0.62
Quad	Suzuki	Kingquad 400ASI	TS57203	46.8	1.06	51.5	1.26	51.5	1.26	39.0	0.81	41.6	0.89	41.6	0.89	42.0	0.90	43.0	0.93	43.0	0.93	35.1	0.70	37.5	0.77	37.5	0.77	33.2	0.65	34.3	0.68	34.3	0.68
Quad	kawasaki	KVF300	TS57204	49.1	1.15	50.8	1.23	50.8	1.23	37.2	0.76	38.3	0.79	38.3	0.79	38.3	0.79	39.6	0.83	39.6	0.83	34.6	0.69	36.1	0.73	36.1	0.73	33.7	0.67	35.2	0.71	35.2	0.71
Quad	Kymco	MXU300	TS57205	48.0	1.11	50.0	1.19	50.0	1.19	36.6	0.74	38.0	0.78	38.0	0.78	37.9	0.78	39.2	0.82	39.2	0.82	34.4	0.68	35.7	0.72	35.7	0.72	32.7	0.64	34.6	0.69	34.6	0.69
Quad	CF Moto	CF500	TS57206	49.5	1.17	50.3	1.20	50.3	1.20	42.3	0.91	42.8	0.93	42.8	0.93	41.5	0.88	43.6	0.95	43.6	0.95	37.3	0.76	39.5	0.82	39.5	0.82	36.2	0.73	38.4	0.79	38.4	0.79
Quad	Can-am	DS90X	TS57211	52.6	1.31	52.9	1.32	52.9	1.32	41.7	0.89	41.9	0.90	41.9	0.90																		
Quad	Yamaha	YFM250R Raptor	TS57212	52.9	1.32	52.8	1.32	52.9	1.32	36.0	0.73	36.3	0.73	36.3	0.73																		
Quad	Honda	TRX700XX	TS57213	47.0	1.07	49.6	1.17	49.6	1.17	37.1	0.76	38.4	0.79	38.4	0.79																		
Quad	Honda	TRX250 + Quadbar	TS57199+CPD1	48.6	1.13	47.9	1.11	48.6	1.13	36.0	0.73	35.7	0.72	36.0	0.73	37.6	0.77	37.3	0.76	37.6	0.77	33.5	0.66	33.2	0.65	33.5	0.66	31.3	0.61	31.9	0.62	31.9	0.62
Quad	Honda	TRX250 + Lifeguard	TS57199+CPD2	46.4	1.05	45.4	1.01	46.4	1.05	35.0	0.70	35.0	0.70	35.0	0.70	36.6	0.74	36.4	0.74	36.6	0.74	34.6	0.69	34.3	0.68	34.6	0.69	32.8	0.64	32.8	0.64	32.8	0.64
Quad	Honda	TRX250 + Quickfix	TS57199+CPD3	44.1	0.97	42.9	0.93	44.1	0.97	34.7	0.69	34.7	0.69	34.7	0.69	34.8	0.70	34.5	0.69	34.8	0.70	33.2	0.65	33.4	0.66	33.4	0.66	33.1	0.65	32.7	0.64	33.1	0.65
Quad	Kymco	MXU300 + Quadbar	TS57205+CPD1	45.7	1.02	47.8	1.10	47.8	1.10	35.5	0.71	36.8	0.75	36.8	0.75	36.7	0.75	38.4	0.79	38.4	0.79	32.9	0.65	34.5	0.69	34.5	0.69	31.6	0.62	33.5	0.66	33.5	0.66
Quad	Kymco	MXU300 + Lifeguard	TS57205+CPD2	43.6	0.95	45.4	1.01	45.4	1.01	34.1	0.68	35.8	0.72	35.8	0.72	35.8	0.72	37.3	0.76	37.3	0.76	34.0	0.67	35.2	0.71	35.2	0.71	32.5	0.64	33.9	0.67	33.9	0.67
Quad	Kymco	MXU300 + Quickfix	TS57205+CPD3	40.9	0.87	43.5	0.95	43.5	0.95	34.0	0.67	35.4	0.71	35.4	0.71	34.4	0.68	35.8	0.72	35.8	0.72	33.0	0.65	34.4	0.68	34.4	0.68	32.9	0.65	34.2	0.68	34.2	0.68
Quad	CF Moto	CF500 + Quadbar	TS57206+CPD1	49.3	1.16	49.7	1.18	49.7	1.18	41.4	0.88	42.2	0.91	42.2	0.91	42.5	0.92	43.0	0.93	43.0	0.93	38.8	0.80	38.8	0.80	38.8	0.80	37.4	0.76	37.8	0.78	37.8	0.78
Quad	CF Moto	CF500 + Lifeguard	TS57206+CPD2	47.3	1.08	48.2	1.12	48.2	1.12	40.9	0.87	41.3	0.88	41.3	0.88	40.8	0.86	41.9	0.90	41.9	0.90	38.4	0.79	39.3	0.82	39.3	0.82	37.4	0.76	38.3	0.79	38.3	0.79
Quad	CF Moto	CF500 + Quickfix	TS57206+CPD3	46.0	1.04	46.6	1.06	46.6	1.06	39.5	0.82	40.3	0.85	40.3	0.85	40.1	0.84	40.5	0.85	40.5	0.85	37.7	0.77	38.1	0.78	38.1	0.78	37.0	0.75	37.7	0.77	37.7	0.77
SSV	Yamaha	YXR Rhino	TS57207	48.3	1.12	55.4	1.45	55.4	1.45	52.2	1.29	53.2	1.34	53.2	1.34													43.8	0.96	45.4	1.01	45.4	1.01
SSV	Kubota	RTV500	TS57208	52.1	1.28	46.1	1.04	52.1	1.28	49.9	1.19	44.5	0.98	49.9	1.19													41.0	0.87	36.8	0.75	41.0	0.87
SSV	John Deere	XUV825i	TS57209	58.0	1.60	55.0	1.43	58.0	1.60	56.2	1.49	50.5	1.21	56.2	1.49													43.9	0.96	38.4	0.79	43.9	0.96
SSV	Honda	MUV700 Big Red	TS57210	58.9	1.66	56.6	1.52	58.9	1.66	55.9	1.48	50.5	1.21	55.9	1.48													40.4	0.85	40.2	0.85	40.4	0.85
SSV	Tomcar	TM2	TS57620	42.3	0.91	47.1	1.08	47.1	1.08	42.3	0.91	46.0	1.04	46.0	1.04													34.1	0.68	37.5	0.77	37.5	0.77

= no load rack, not tested in this configuration.

Note: The point of tipover is the point at which both high side wheels (front) have lifted from the table

Note: Tilt Table Ratio (TTR) is equal to the Tangent of the angle at which both high side wheels have left the table (point of tipover)

Data traces of load-angle for the high side wheels for each test are located in Appendix C of this report.

5 Discussion

5.1 Lateral roll

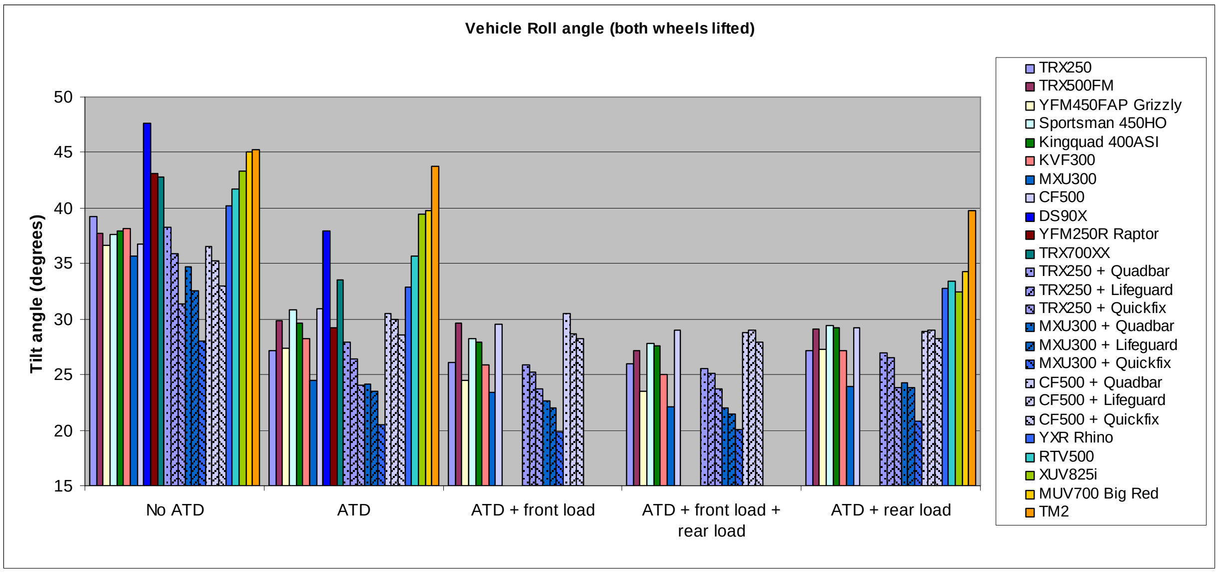


Figure 2: Results (roll) – vehicle roll angle, all vehicles, all load conditions

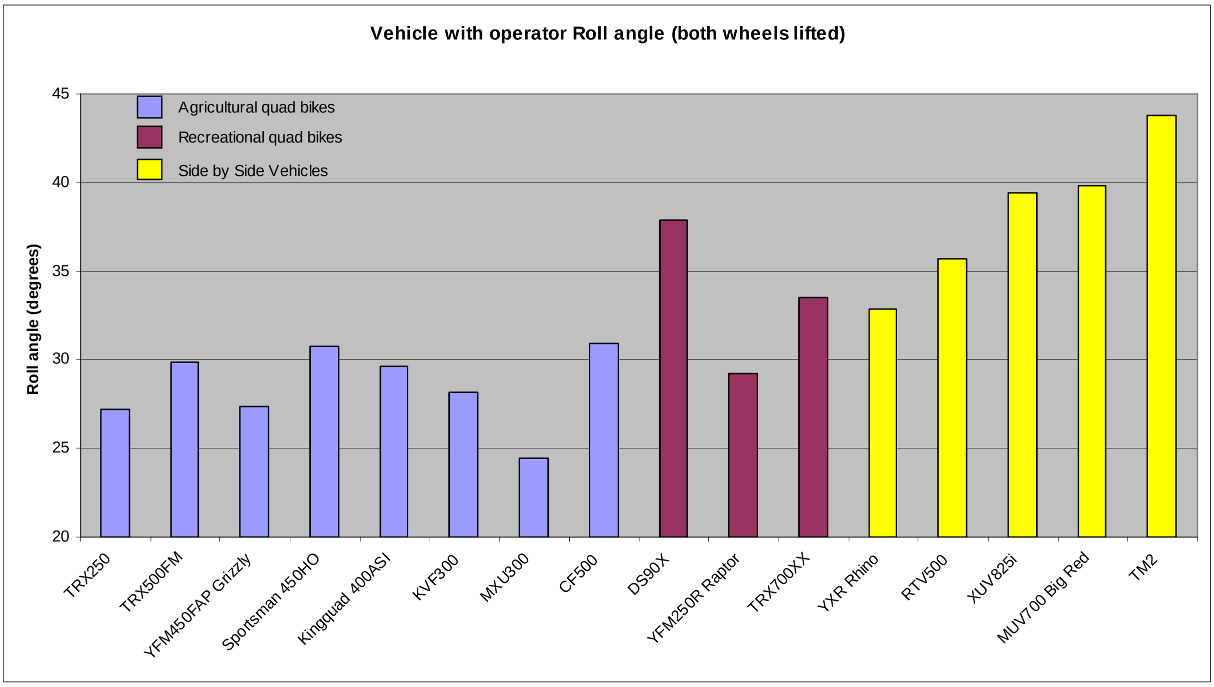


Figure 3: Results (roll) – vehicle roll angle with operator, grouped by vehicle type

The lateral roll angles achieved ranged from 19.8° in the worst performing test to 47.6° in the best performing test.

Tested in the configuration with a single operator and no cargo load, the rollover angle ranged from 24.5° to 43.8°.

The Tilt Table Ratio (TTR) is calculated as the Tangent of the angle at which both high side wheels have left the table (point of rollover), see section 5.4 for more details. The TTR and Tilt angle ranges are tabled below for the three vehicle types and five load conditions when subjected to lateral roll.

Load condition	Vehicle type	Tilt Table Ratio (TTR)	Tilt angle
Base line (no operator, no load)	Agricultural quad bikes (8)	TTR = 0.72 to 0.82	35.7° to 39.2°
	Recreational quad bikes (3)	TTR =0.93 to 1.10	42.8° to 47.6°
	Side by side vehicles (5)	TTR =0.85 to 1.01	40.2° to 45.3°
Operator only	Agricultural quad bikes (8)	TTR =0.46 to 0.60	24.5° to 30.8°
	Recreational quad bikes (3)	TTR =0.56 to 0.78	29.2° to 37.8°
	Side by side vehicles (5)	TTR =0.65 to 0.96	32.9° to 43.8°
Operator plus rear load	Agricultural quad bikes (8)	TTR =0.44 to 0.56	23.9° to 29.4°
	Side by side vehicles (5)	TTR =0.64 to 0.83	32.5° to 39.8°
Operator plus front load	Agricultural quad bikes (8)	TTR =0.43 to 0.57	23.4° to 29.6°
Operator plus front load and rear load	Agricultural quad bikes (8)	TTR =0.41 to 0.55	22.2° to 29.0°

Table 5 – Tilt Table Ratio (TTR) and Tilt angle ranges (lateral roll)

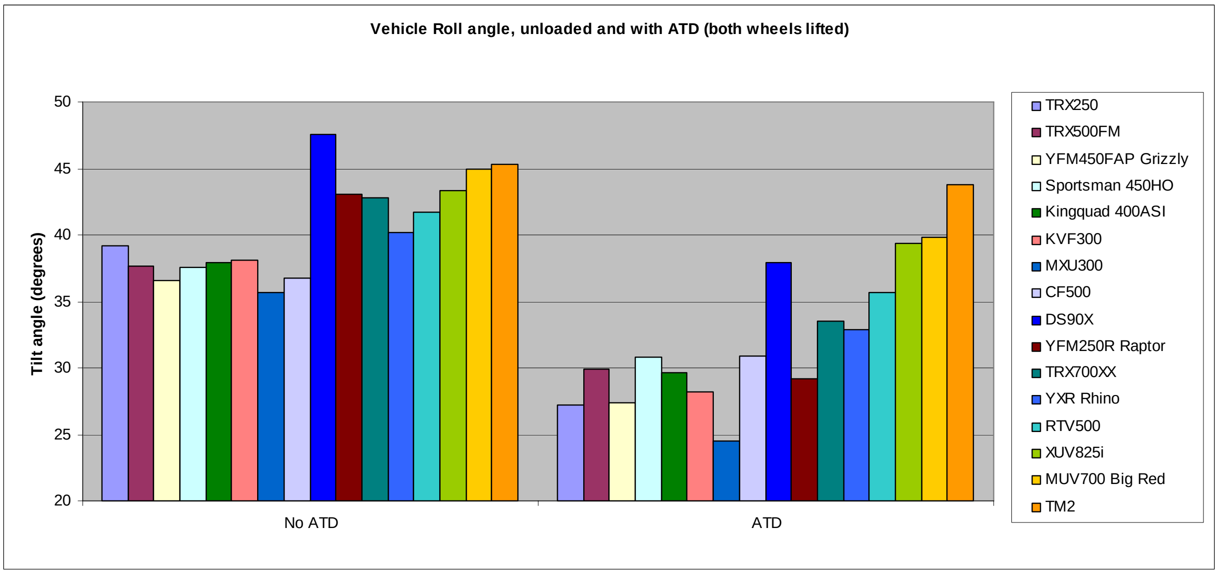


Figure 4: Results (roll) – Vehicle roll angle, unloaded, with ATD

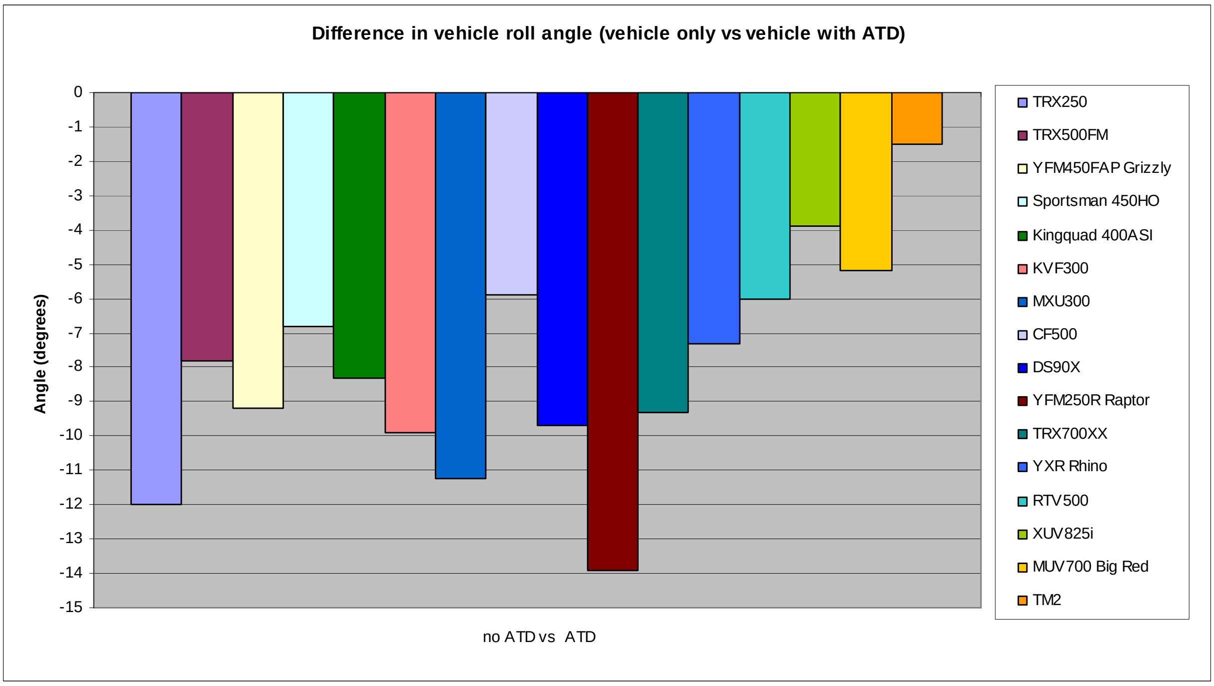


Figure 5: Results (roll) – Difference in vehicle roll angle, unloaded vs with ATD

All vehicles tested had a lower rollover angle when the operator load (ATD) was applied to the vehicle. The operator mass reduced the rollover angle by between 1.5° and 13.9°.

The lightest vehicle tested with the 95th%ile ATD was the vehicle that had the greatest reduction in rollover angle. The two heaviest vehicles were the vehicles least affected by the addition of the operator mass.

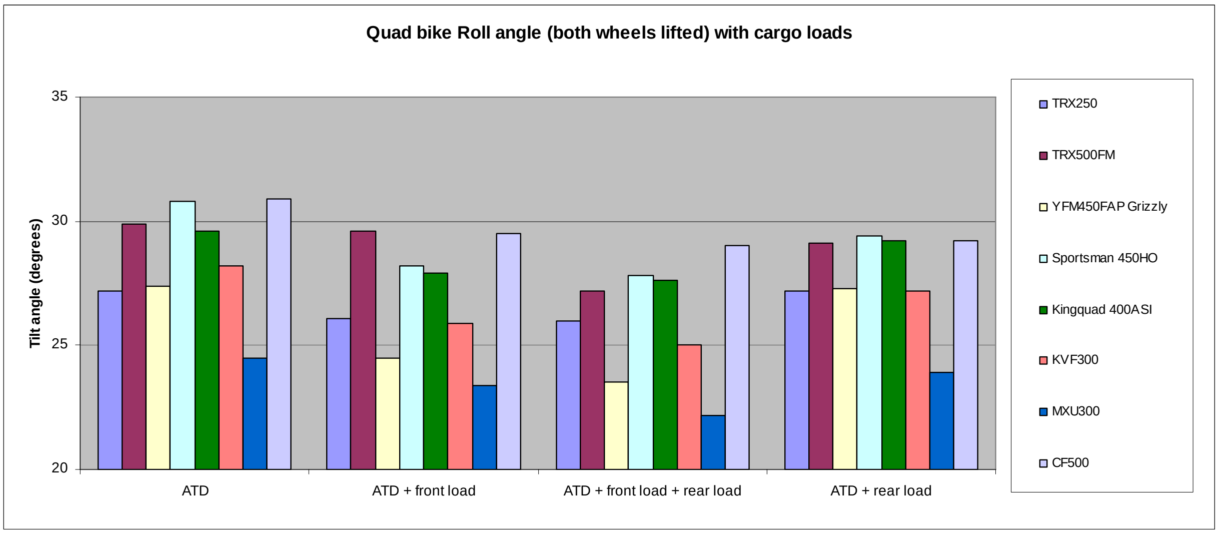


Figure 6: Results (roll) – Quad bike roll angle, different load configurations

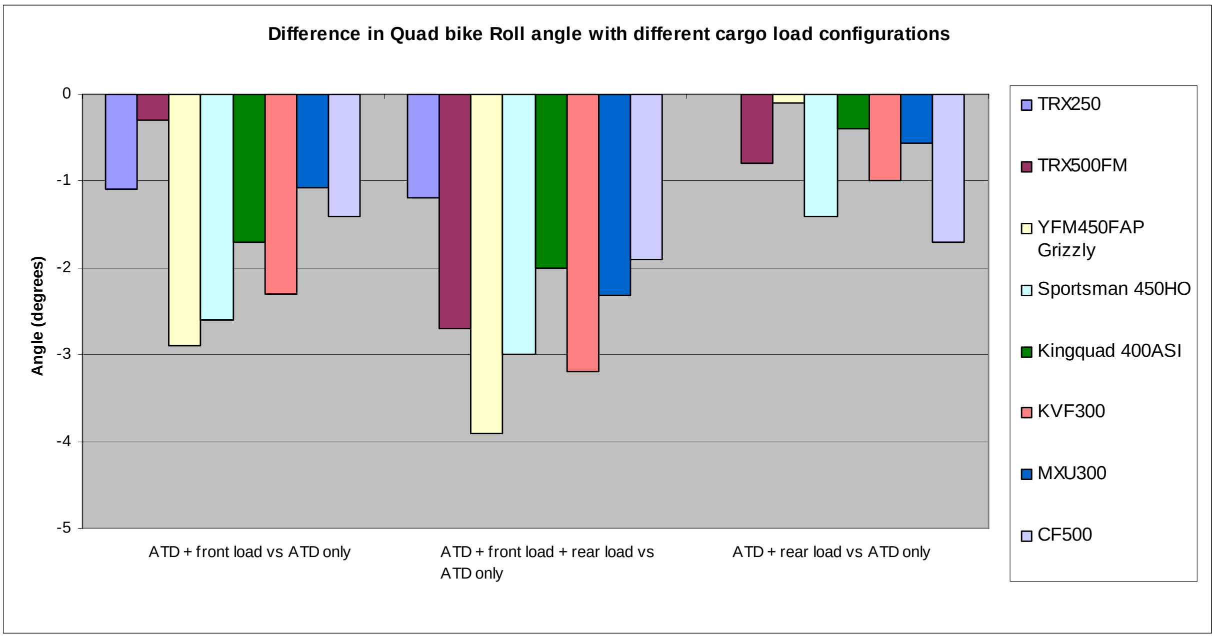


Figure 7: Results (roll) – Difference in quad bike roll angle, different load configurations

When compared to a quad bike with only an operator (no cargo load), applying a cargo load to the quad bikes reduced the angle at which rollover occurred by between zero and 3.9˚.

Applying a front load alone reduced the rollover angle by 0.3° to 2.9°.

Applying a rear load alone reduced the rollover angle by 0° to 1.7°.

Applying both a front and rear cargo load had the greatest effect on rollover angle with a reduction in rollover angle of between 1.2° and 3.9°.

In general the reduction in rollover angle was more sensitive to the addition of front load.

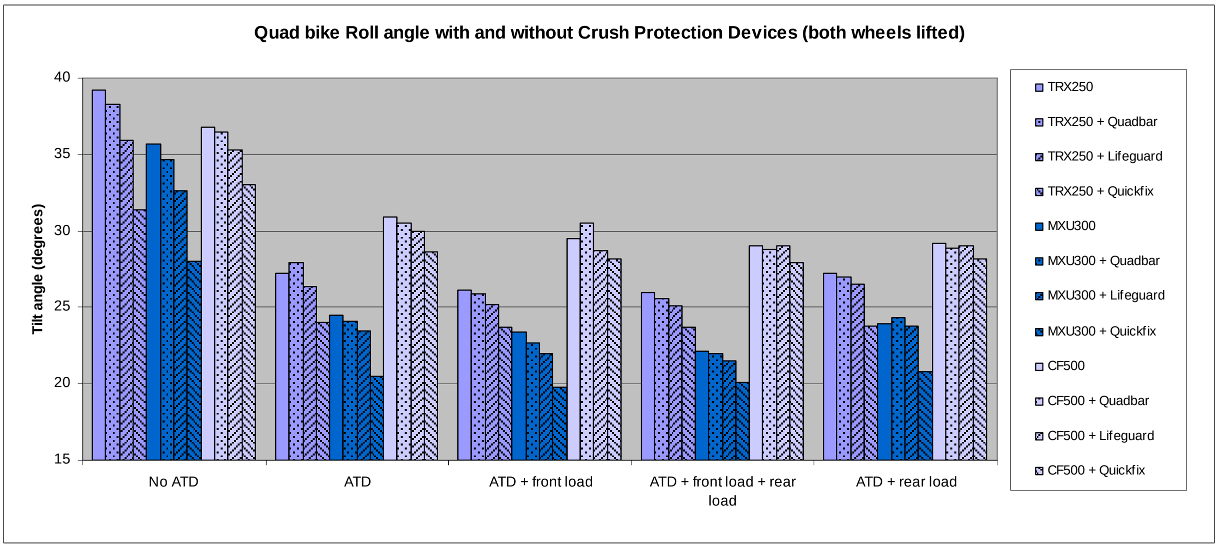


Figure 8: Results (roll) – Quad bike roll angle, three CPDs, different load configurations

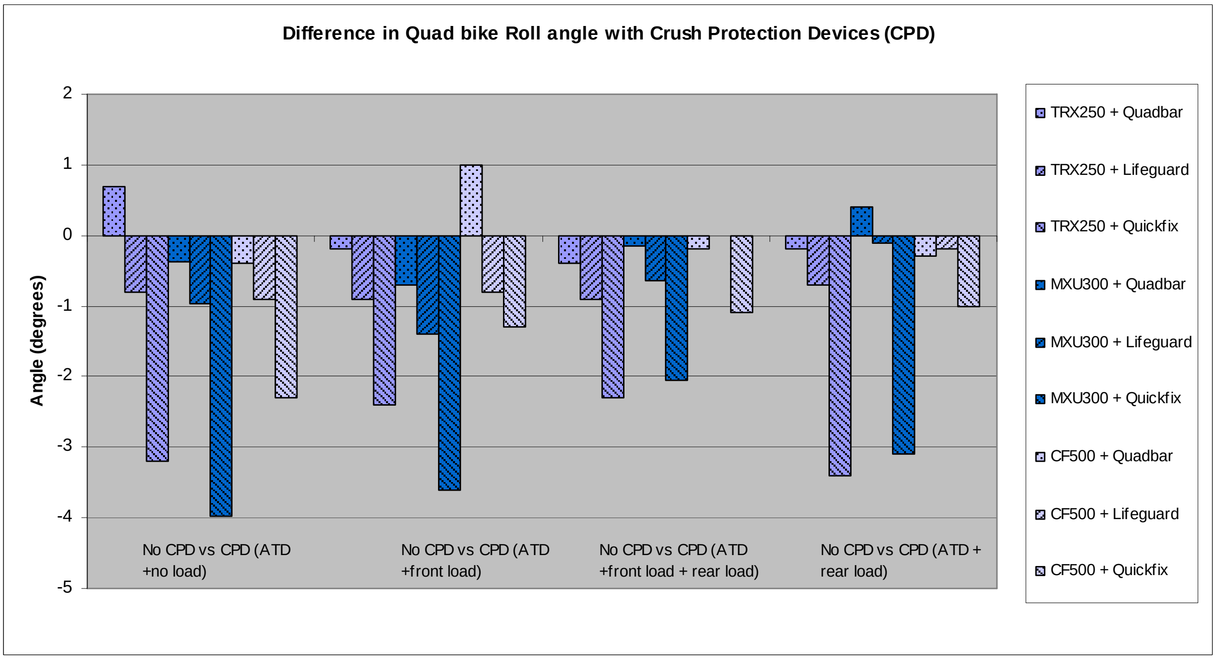


Figure 9: Results (roll) – Difference in quad bike roll angle, three CPDs, different load configurations

By fitting the Quadbar CPD (8.5kg) to three different quad bikes (the highest, lowest and median performing bikes), the rollover angle threshold varied from a reduction of 0.7° to an increase of 1.0°.

By fitting a Lifeguard CPD (14.8kg) to the same three quad bikes, the rollover angle was reduced by between 0.0° and 1.4°.

By fitting a Quick-fix CPD (30.0kg) to the same three quad bikes, the rollover angle was reduced by between 1.0° and 4.0°.

5.2 Forward pitch

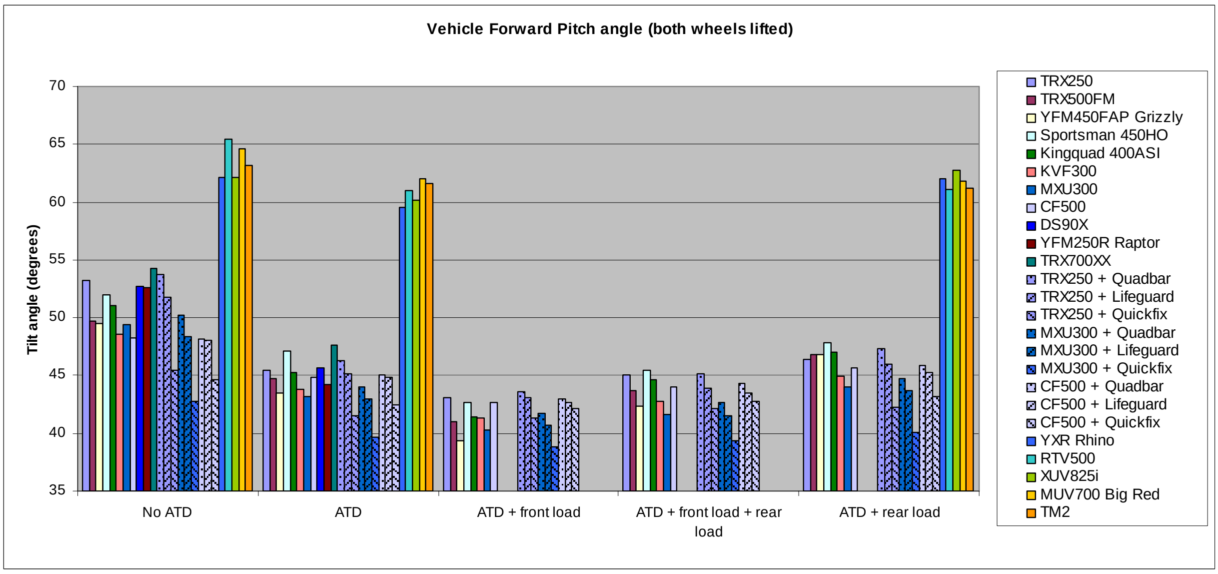


Figure 10: Results (forward pitch) – vehicle tilt angle, all vehicles, all load conditions

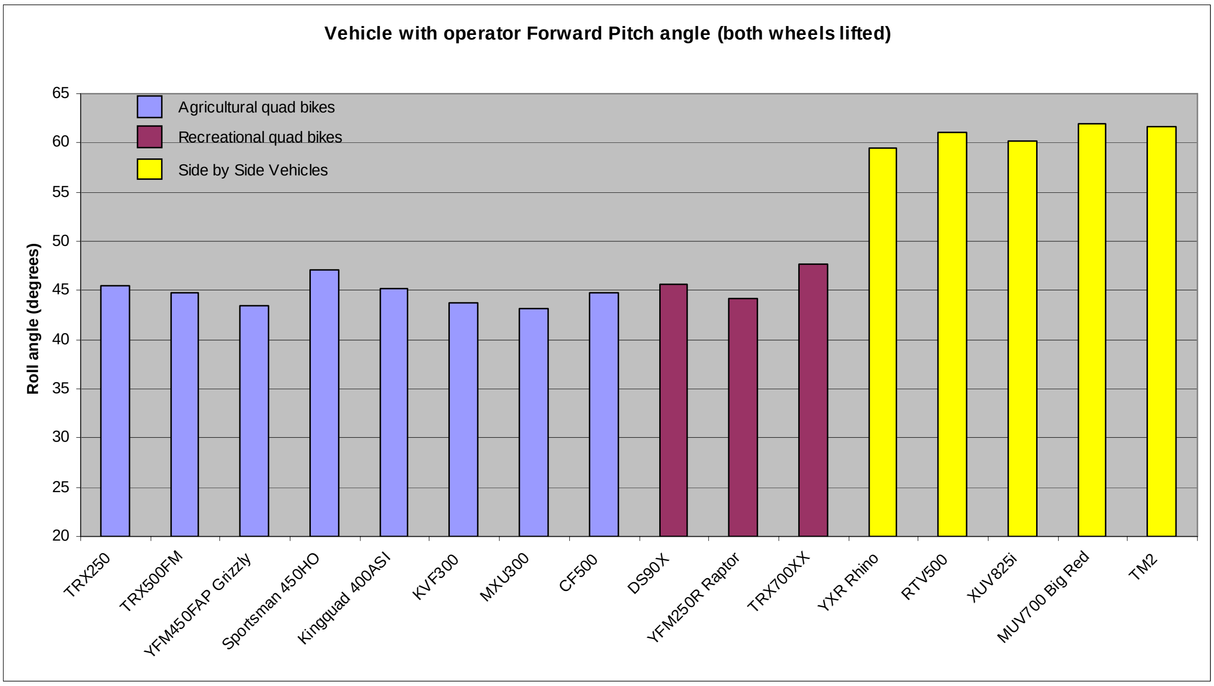


Figure 11: Results (forward pitch) – vehicle tilt angle with operator, grouped by vehicle type

The forward pitch angle achieved ranged from 38.8° in the lowest performing test to 65.4° in the highest performing test.

Tested with a single operator and no cargo load, the forward tilt angle ranged from 43.2° to 62.0°.

The Tilt Table Ratio (TTR) is calculated as the Tangent of the angle at which both high side wheels have left the table (point of tipover). The TTR and Tilt angle ranges are tabled below for the three vehicle types and five load conditions when subjected to forward pitch.

Load condition	Vehicle type	Tilt Table Ratio (TTR)	Tilt angle
Base line (no operator, no load)	Agricultural quad bikes (8) Recreational quad bikes (3) Side by side vehicles (5)	TTR = 1.12 to 1.34 TTR =1.31 to 1.39 TTR =1.89 to 2.18	48.3° to 53.2° 52.6° to 54.3° 62.1° to 65.4°
Operator only	Agricultural quad bikes (8) Recreational quad bikes (3) Side by side vehicles (5)	TTR =0.94 to 1.08 TTR =0.97 to 1.10 TTR =1.70 to 1.88	43.2° to 47.1° 44.2° to 47.6° 59.5° to 62.0°
Operator plus rear load	Agricultural quad bikes (8) Side by side vehicles (5)	TTR =0.97 to 1.10 TTR =1.81 to 1.95	44.0° to 47.8° 61.1° to 62.8°
Operator plus front load	Agricultural quad bikes (8)	TTR =0.82 to 0.94	39.3° to 43.1°
Operator plus front load and rear load	Agricultural quad bikes (8)	TTR =0.89 to 1.02	41.6° to 45.5°

Table 6 – Tilt Table Ratio (TTR) and Tilt angle ranges (forward pitch)

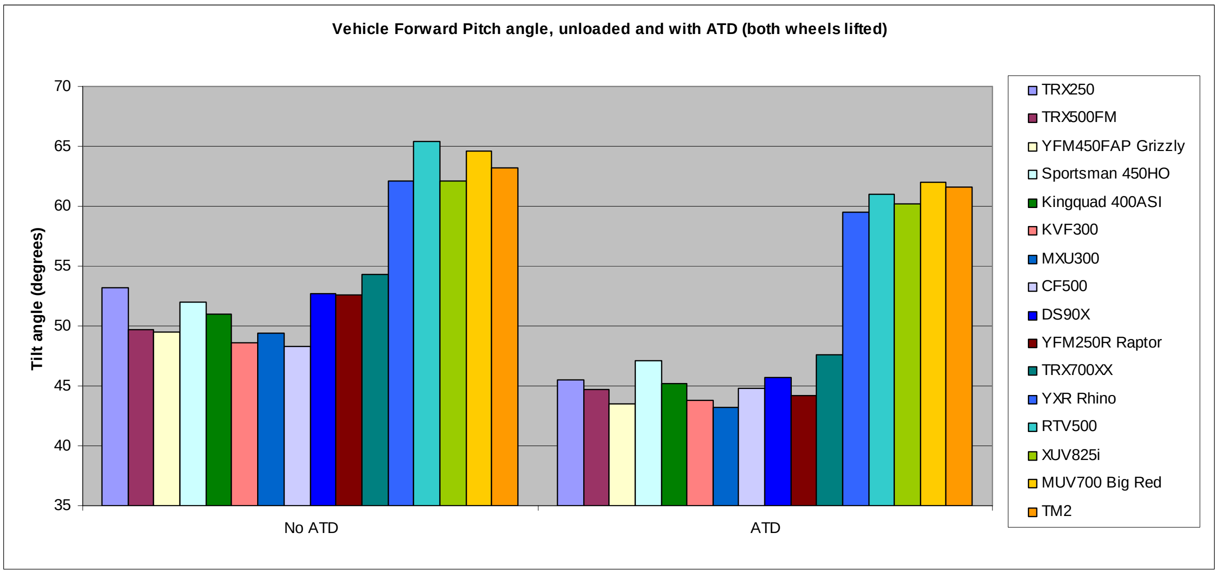


Figure 12: Results (forward pitch) – Vehicle tilt angle, unloaded, with ATD

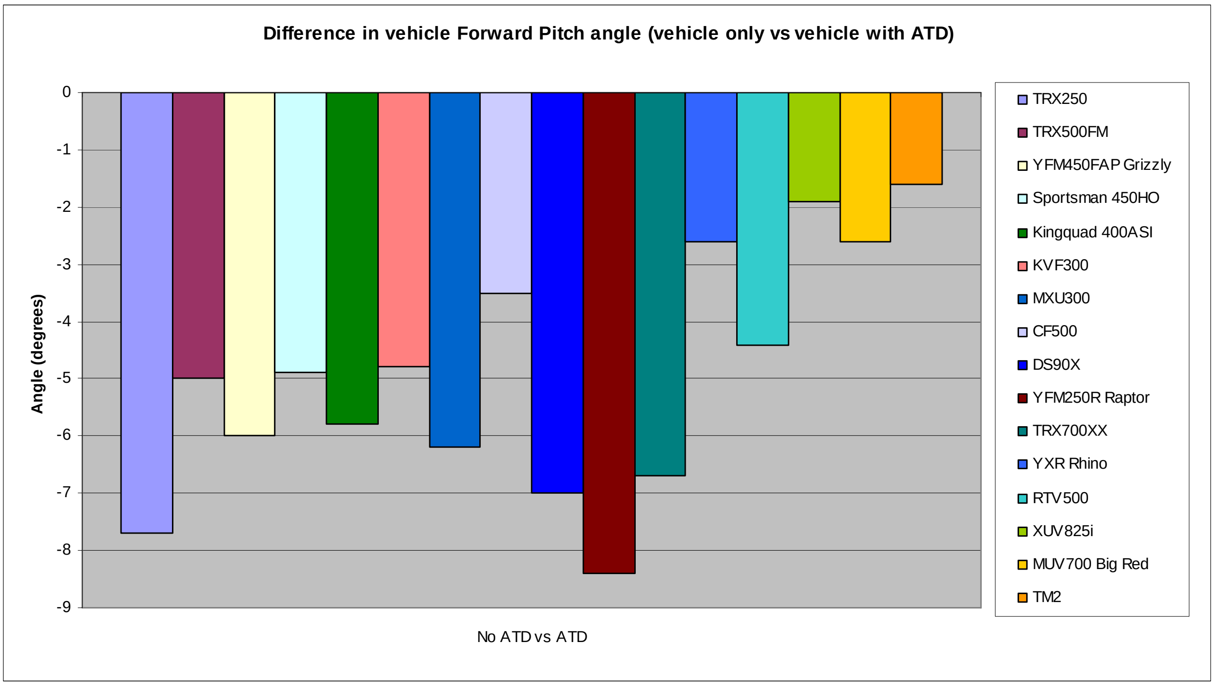


Figure 13: Results (forward pitch) – Difference in vehicle tilt angle, unloaded vs with ATD

All vehicles tested had a lower forward pitch-over angle when the operator load was applied to the vehicle. The operator mass reduced the tip-over angle by between 1.6° and 8.4°.

The lightest vehicle tested with the 95th%ile ATD was the vehicle that had the greatest reduction in tipover angle. The two heaviest vehicles were the vehicles least affected by the addition of the operator mass.

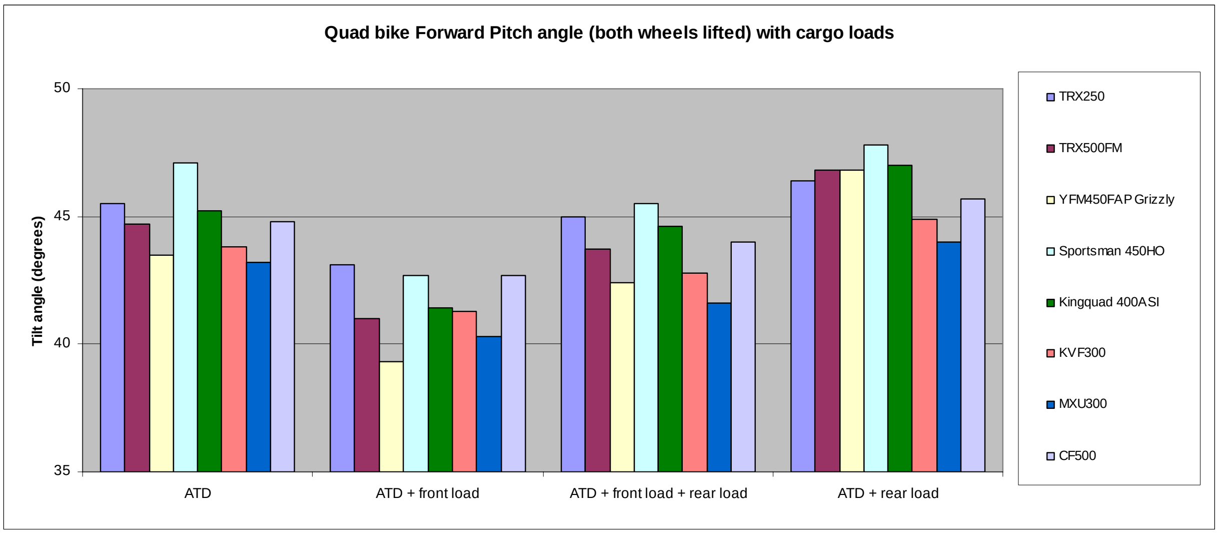


Figure 14: Results (forward pitch) – Quad bike tilt angle, different load configurations

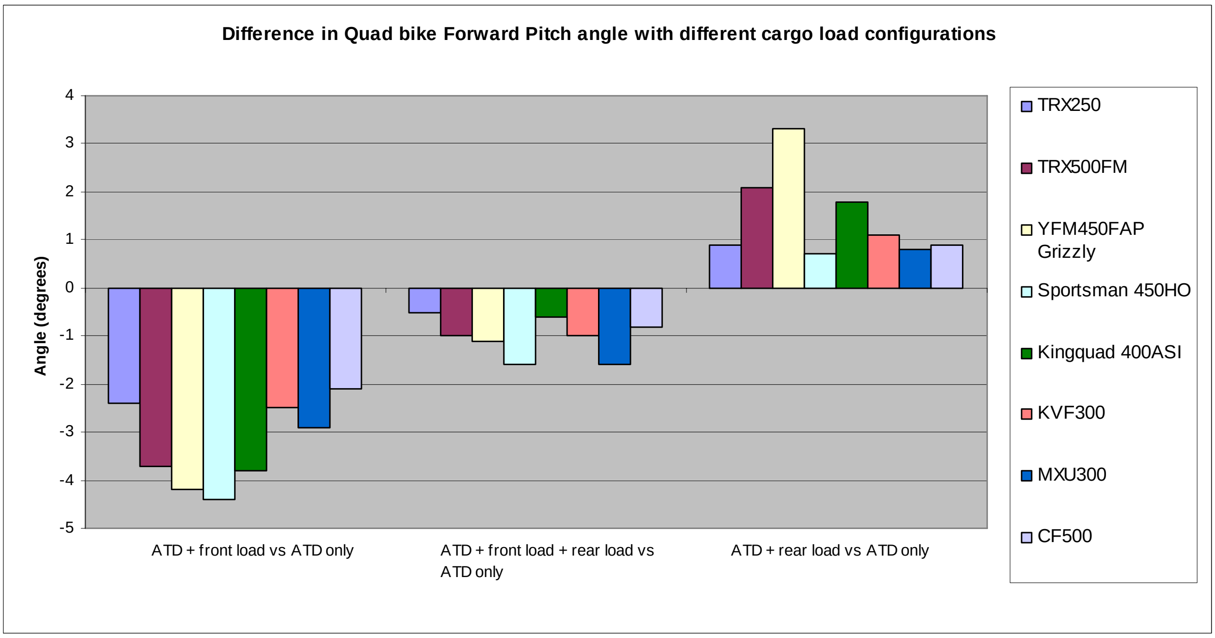


Figure 15: Results (forward pitch) – Difference in quad bike tilt angle, different load configurations

Applying only a front cargo load had the adverse effect of reducing the forward pitch over angle by between 2.1° and 4.4°.

Applying a front and rear load had the adverse effect of reducing the pitch over angle by 0.5° to 1.6°.

Applying only a rear load increased the pitch over angle by 0.7° to 3.3°

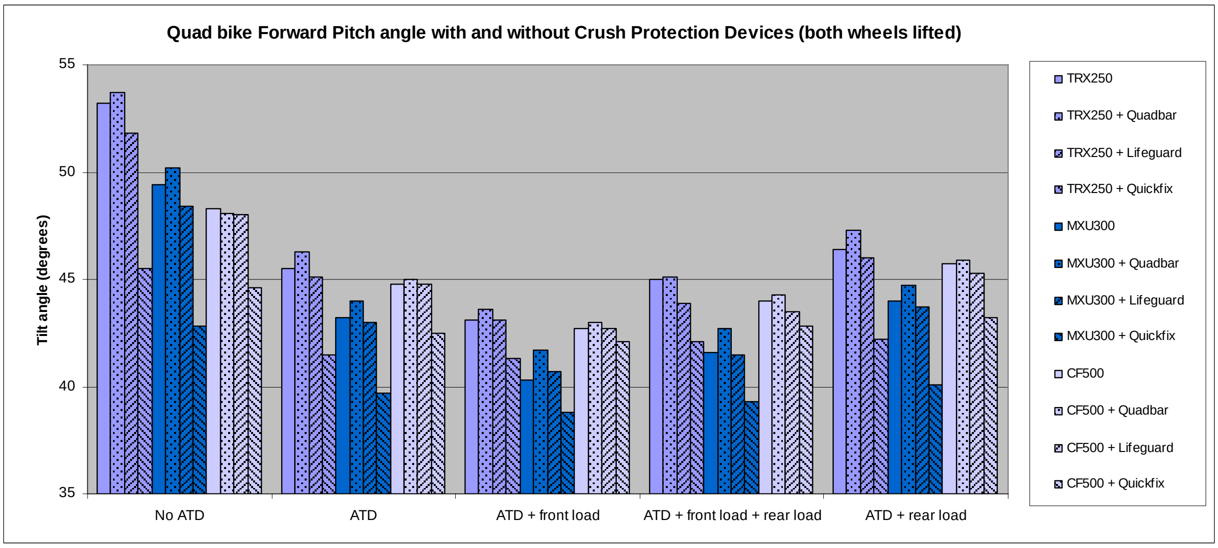


Figure 16: Results (forward pitch) – Quad bike tilt angle, three CPDs, different load configurations

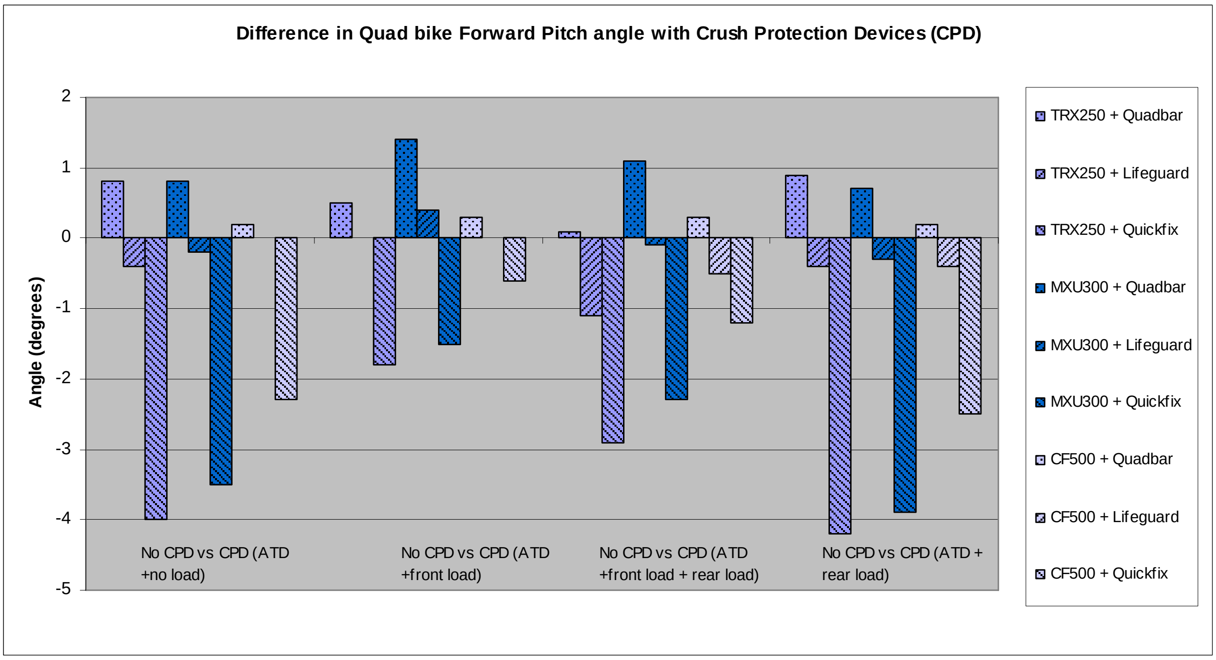


Figure 17: Results (forward pitch) – Difference in quad bike roll angle, three CPDs, different load configurations

By fitting a Quadbar CPD (8.5kg) to three different quad bikes, the forward pitch-over angle was increased by between 0.1° and 1.4°.

By fitting a Lifeguard CPD (14.8kg) to the same three quad bikes, the forward pitch-over angle was increased by up to 0.4° and reduced by up to 1.1°.

By fitting a Quick-fix CPD (30.0kg) to the same three quad bikes, the forward pitch-over angle was reduced by between 1.2° and 4.2°.

5.3 Rearward pitch

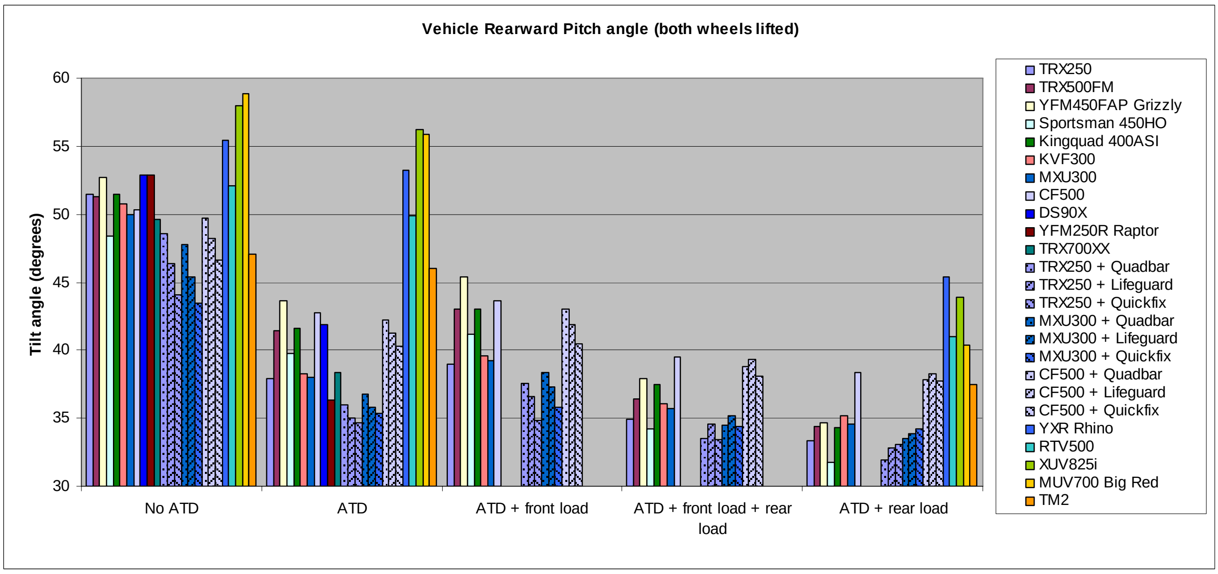


Figure 18: Results (rearward pitch) – vehicle tilt angle, all vehicles, all load conditions

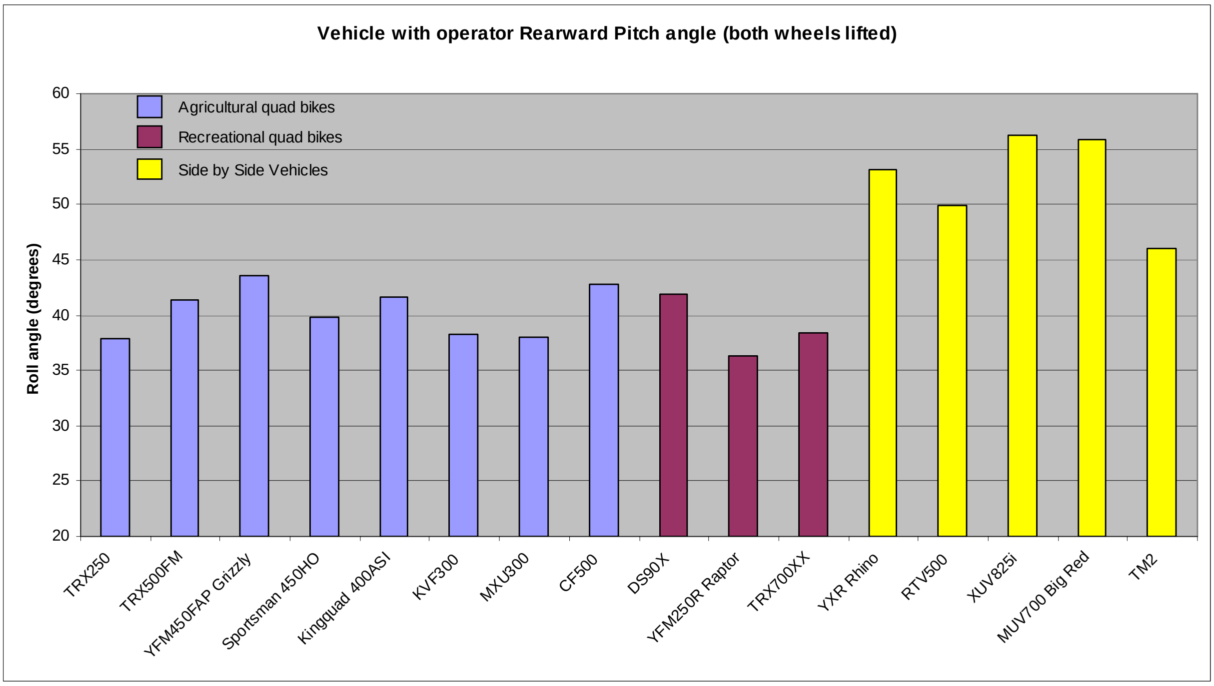


Figure 19: Results (rearward pitch) – vehicle tilt angle with operator, grouped by vehicle type

The rearward pitch angle ranged from 31.8° in the lowest performing test to 58.9° in the best performing test.

Tested with a single operator and no cargo load, the rearward pitch angle ranged from 36.3° to 56.2°.

The Tilt Table Ratio (TTR) is calculated as the Tangent of the angle at which both high side wheels have left the table (point of tipover). The TTR and Tilt angle ranges are tabled below for the three vehicle types and five load conditions when subjected to rearward pitch.

Load condition	Vehicle type	Tilt Table Ratio (TTR)	Tilt angle
Base line (no operator, no load)	Agricultural quad bikes (8) Recreational quad bikes (3) Side by side vehicles (5)	TTR = 1.13 to 1.31 TTR = 1.17 to 1.32 TTR = 1.08 to 1.66	48.4° to 52.7° 49.6° to 52.9° 47.1° to 58.9°
Operator only	Agricultural quad bikes (8) Recreational quad bikes (3) Side by side vehicles (5)	TTR = 0.78 to 0.95 TTR = 0.73 to 0.90 TTR = 1.04 to 1.49	37.9° to 43.6° 36.3° to 41.9° 46.0° to 56.2°
Operator plus rear load	Agricultural quad bikes (8) Side by side vehicles (5)	TTR = 0.62 to 0.79 TTR = 0.77 to 1.01	31.8° to 38.4° 37.5° to 45.4°
Operator plus front load	Agricultural quad bikes (8)	TTR = 0.81 to 1.01	39.0° to 45.4°
Operator plus front load and rear load	Agricultural quad bikes (8)	TTR = 0.68 to 0.82	34.2° to 39.5°

Table 7 – Tilt Table Ratio (TTR) and Tilt angle ranges (rearward pitch)

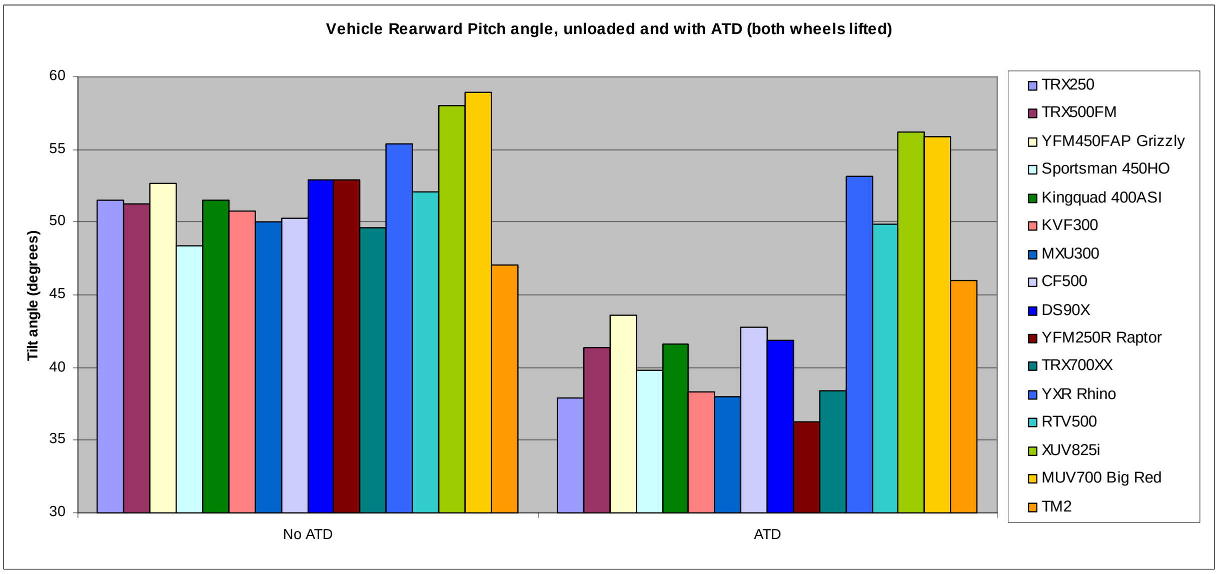


Figure 20: Results (rearward pitch) – Vehicle tilt angle, unloaded, with ATD

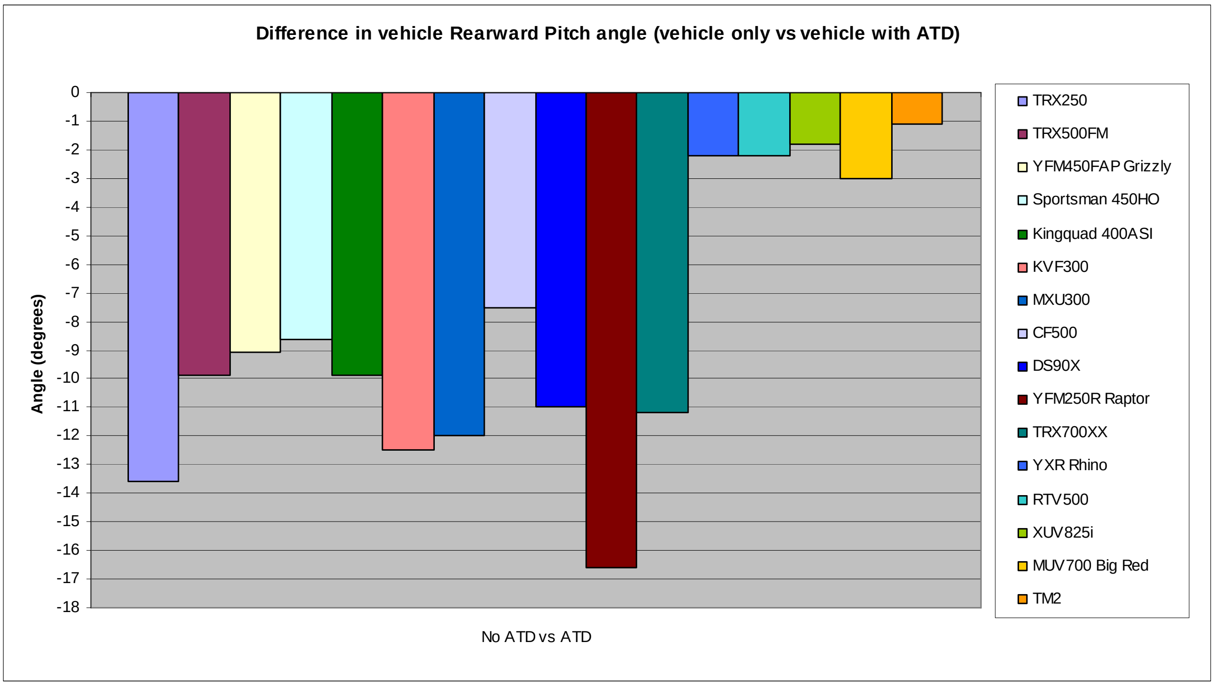


Figure 21: Results (rearward pitch) – Difference in vehicle tilt angle, unloaded vs with ATD

All vehicles tested had a lower rearward pitch angle when the ATD (vehicle operator) mass was applied to the vehicle. The ATD mass reduced the rollover angle by between 1.1° and 16.6°.

The lightest vehicle tested with the 95th%ile ATD was the vehicle that had the greatest reduction in rollover angle. The two heaviest vehicles were the vehicles least affected by the addition of the ATD mass.

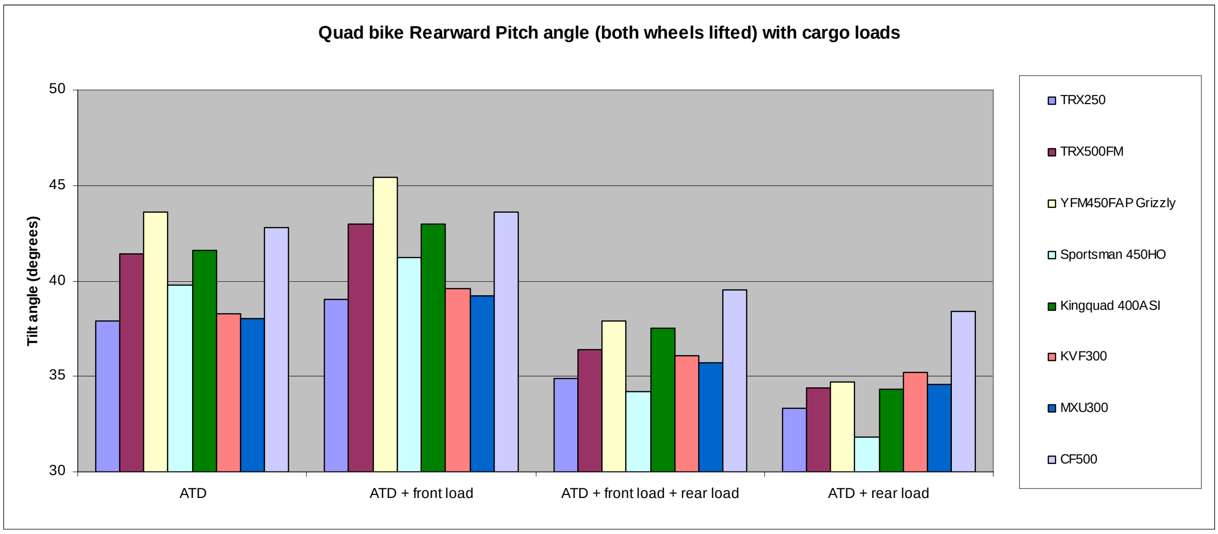


Figure 22: Results (rearward pitch) – Quad bike tilt angle, different load configurations

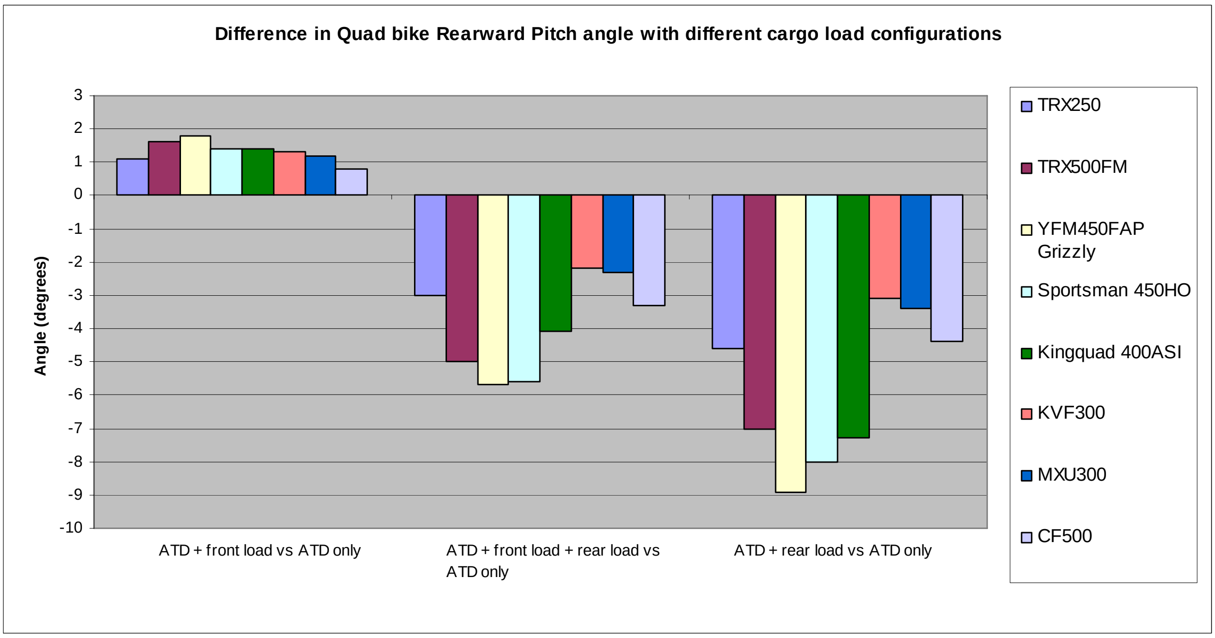


Figure 23: Results (rearward pitch) – Difference in quad bike tilt angle, different load configurations

Applying a cargo load to the front rack of the quad bikes increased the rearward pitch-over angle by between 0.8 and 1.8°.

Applying a cargo load to the rear rack, or both front and rear load racks of the quad bikes decreased the forward pitch over angle by between 2.2 and 8.9°.

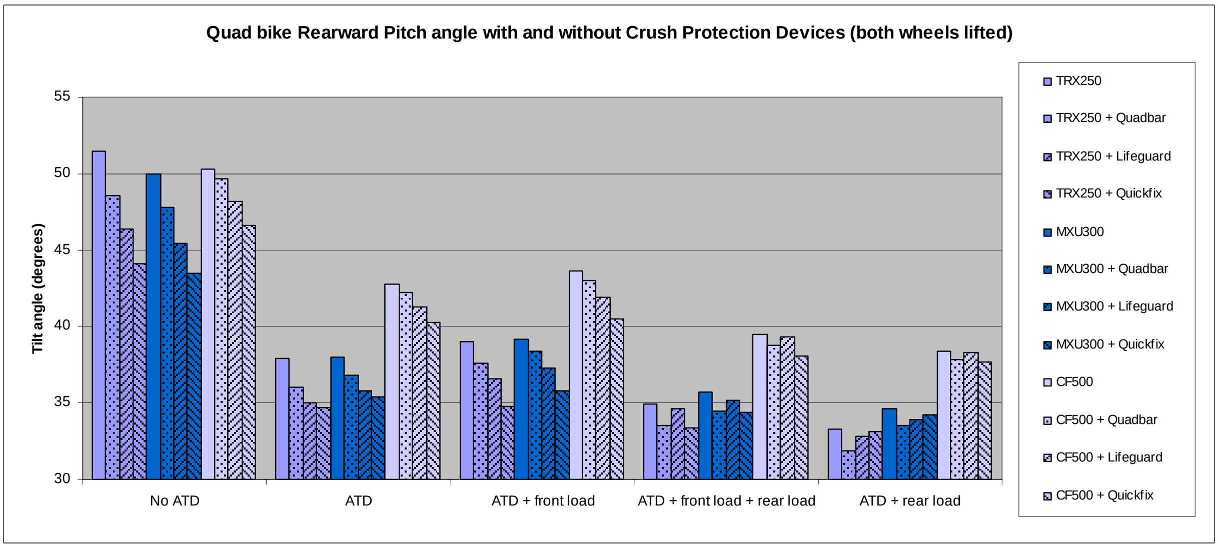


Figure 24: Results (rearward pitch) – Quad bike tilt angle, three CPDs, different load configurations

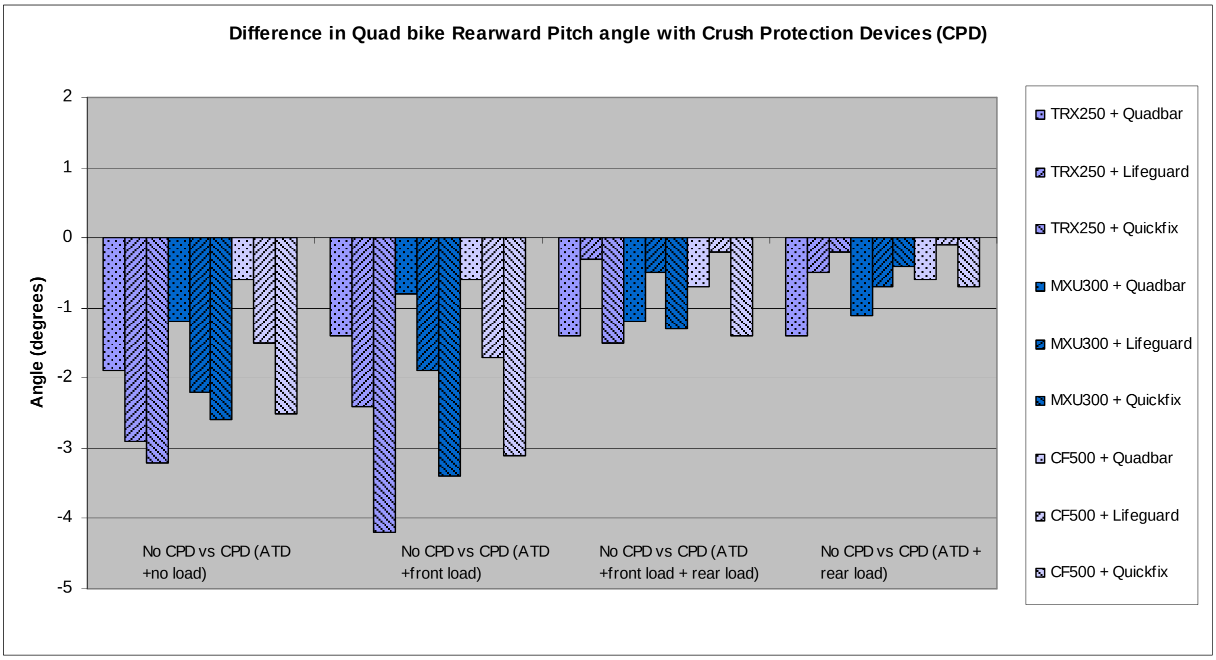


Figure 25: Results (rearward pitch) – Difference in quad bike roll angle, three CPDs, different load configurations

By fitting a Quadbar CPD (8.5kg) to three different quad bikes, the rearward pitch-over angle was decreased by between 0.6° and 1.9°.

By fitting a Lifeguard CPD (14.8kg) to the same three quad bikes, the rearward pitch-over angle was reduced by between 0.1° and 2.9.

By fitting a Quick-fix CPD (30.0kg) to the same three quad bikes, the rearward pitch-over angle was reduced by between 0.2° and 4.2°.

5.4 Tilt Table Ratio (TTR)

The Tilt Table Ratio (TTR) is calculated by: $Tan\theta$
Where θ = the angle at which both high side wheels have left the table (point of tip over)

The TTR is a mathematical approximation of the acceleration (in g's) at which rollover or tilt-over would occur.

5.5 Centre Of Gravity (COG) height and static stability factor (Kst)

The height of the Centre Of Gravity (COG) of the vehicles above the ground plane was calculated by intersecting the vertical line through the vehicle at the point of tip-over in forward and rearward pitch in the unloaded (kerb mass) condition.

The static stability factor (Kst) is a measure of vehicle lateral stability determined from the American National Standard for Recreational Off-Highway Vehicles ANSI/ROHVA 1-2011 [1] by the formula:

$$Kst = \frac{Lt_2 + L_{cg}(t_1 - t_2)}{2LH_{cg}}$$

Where:
L_{cg} = Location of COG forward of rear axle
H_{cg} = Location of COG above ground plane
t_1 = Front track width
t_2 = Rear track width
L = Wheelbase
The performance requirement from ANSI/ROHVA 1-2011 states that Kst shall be no less than 1.0.

The calculated COG and Kst values for the vehicles are tabled below:

Vehicle	COG height (mm)	Static stability factor (Kst)
Honda Fourtrax TRX250	436	0.9
Honda Foreman TRX500FM	528	0.9
Yamaha Grizzly YFM450FAP	496	0.9
Polaris Sportsman 450HO	533	0.9
Suzuki Kingquad 400ASI	510	0.9
Kawasaki KVF300	494	0.9
Kymco MXU300	492	0.8
CF Moto CF500	554	0.8
Can-am DS90X	389	1.2
Yamaha Raptor YFM250R	422	1.0
Honda TRX700XX	491	1.0
Yamaha Rhino YXR700	572	1.0
Kubota RTV500	519	1.0
John Deere Gator XUV825i	576	1.1
Honda Big Red MUV700	511	1.3
Tomcar TM-2	671	1.1

Table 8 – Centre of Gravity (COG) height and static stability factor (Kst) values

6 Conclusions

Eleven quad bikes and five side-by-side vehicles were subjected to tilt testing in the roll, forward pitch and rearward pitch directions.

The vehicles were tested unloaded, with an operator load and with cargo loads. Three of the quad bikes were also tested with three different Crush Protection Devices (CPD) fitted.

The lowest lateral rollover angle for a vehicle with an operator in any load configuration (without a CPD fitted) was an agricultural quad bike at 22.2°. The greatest lateral rollover angle for a vehicle with an operator was an SSV at 43.8°.
The lowest forward pitch-over angle for a loaded vehicle with an operator in any load configuration (without a CPD fitted) was an agricultural quad bike at 39.3°. The greatest forward pitch-over angle for a vehicle with an operator was an SSV at 62.8°.
The lowest rearward pitch-over angle for a loaded vehicle with an operator in any load configuration (without a CPD fitted) was an agricultural quad bike at 31.8°. The greatest rearward pitch-over angle for a vehicle with an operator was an SSV at 56.2°.

Applying cargo loads to the vehicles reduced rollover and tip-over angles, with the exceptions however that in forward tip-over a rear cargo load tended to increase the tip-over angle, and in rearward tip-over a front cargo load increased the tip-over angle.

Each of the three different CPDs had a different magnitude of effect on the rollover and tip-over angles of the quad bikes. The greatest effect that any of the CPDs had on the quad bikes tested was to reduce the forward and rearward tip-over angles by 4.2°

The recreational quad bikes generally showed higher rollover angles than the agricultural quad bikes, but had about the same forward and rearward pitch-over angles.

The Side by Side Vehicles generally demonstrated higher rollover angles than the agricultural quad bikes in all three rollover stability directions tested.

7 Reference Material

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

[2] American National Standards Institute Inc 2012 (sponsored by Outdoor Power Equipment Institute), *American National Standard for Multipurpose Off-Highway Utility Vehicles*, ANSI/OPEI B71.9-2012, American National Standards Institute Inc, New York USA.

[3] Specialty Vehicle Institute of America 2010, *American National Standard for Four Wheel All-Terrain Vehicles*, ANSI/SVIA 1-2010, Specialty Vehicle Institute of America, California USA

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9 Appendices

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

Appendix A
Test Specification

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

1. Test specification

Quad bike performance project – Tilt table quasi-static tilt test specification

Tilt table

- Adjustable slope single plane tilt-able structure, range of 0° to 80° from horizontal
- Surface shall be rigid, flat and large enough to support all four wheels
- Surface shall support a load cell under each of the four vehicle wheels.
- A high friction surface to be installed on the top surface of the low side load cells to prevent the low side tyres from slipping (anti-slip tape or expanded mesh)
- Table tilt rate of nominally less than 1.0 degree per second (for at least 20 degrees before tyre lift-off)

Test vehicle setup

- Vehicle to be prepared to Kerb Mass ie. all standard equipment fitted and vehicle fluids to be filled to maximum capacity (engine oil, transmission and differential fluids, coolant and fuel)
- Tyres to be inflated to manufacturer recommended pressure. Where a range of pressures is nominated, inflate to the lower pressure
- Adjustable suspension to be set at values specified at dealer delivered configuration

Test vehicle loading

- Cargo load shall consist of dry sand (bags) with a nominal density of 1800kg/m^3
- The load shall be distributed uniformly across the load area and secured in place.
- Thin ply wood board which follows the shape of the load rack shall 'sandwich' the load top and bottom (load straps and ply to be accounted for in load mass).
- If multiple cargo areas are present and the sum of the individual load capacities exceed the total vehicle load capacity, the load shall be distributed between the areas as a ratio of the individual load capacities (up to the vehicle load capacity).

Anthropomorphic Test Devices (ATDs)

- For full size quad bikes use Hybrid III 95%ile (nominal mass 101kg) clothed in form fitting cotton clothing and shoes equivalent to those specified in MIL-S13192 rev P
- For youth model quad bikes with operator mass of less than 70kg use Hybrid III 5%ile (nominal mass 49kg) clothed in form fitting cotton clothing and shoes equivalent to those specified in MIL-S13192 rev P
- ATD is to be secured to the seat in a manner to prevent independent movement. The ATD is to remain vertical relative to the vehicle throughout the test (nominally each leg secured to the footrest. Each hand secured to the hand control)
- ATD to be positioned such that; the hands are gripping the hand controls with the web of the hand in contact with the inner ridge of the grip, the arms are fully extended, the pelvis is centred laterally on the seat and located longitudinally such that the back angle is vertical ($\pm$2.5°), the head roll angle is horizontal ($\pm$0.5°), The thighs are to be in contact with the fuel tank, the feet are positioned on the footrest with the heel of the shoe in contact with the rear edge of the footrest. *The ATD pelvis angle and H-point are to be recorded relative to the rear upper edge of the footrest (vertical and horizontal dimensions)*

Static stability coefficient (Kst)

- Record vehicle wheelbase and track width (check against manufacturer supplied documentation)
- In test condition, weight vehicle on flat level surface to obtain the four individual wheel masses and calculate vehicle longitudinal Centre Of Gravity (COG) and lateral COG
- Use scientifically valid method to determine vehicle COG height
- Calculate lateral static stability coefficient using : $K_{st} = \frac{(L \bullet T_2 + L_{cg}(T_1 - T_2))}{2 \bullet L \bullet H_{cg}}$

Where: K_{st} = Lateral static stability coefficient
L = Wheelbase
T_1 = Front track width
T_2 = Rear track width
L_{cg} = Longitudinal distance from rear axle to Centre Of Gravity (COG)
H_{cg} = Height of COG above ground plane

- Calculate longitudinal static stability coefficient using : $K_f = \frac{L_{cgf}}{H_{cg}}$ and $K_r = \frac{L_{cgr}}{H_{cg}}$

Where: K_f = Longitudinal static stability coefficient (frontal)
L_{cgf} = Longitudinal distance from front axle to Centre Of Gravity (COG)
H_{cg} = Height of COG
K_r = Longitudinal static stability coefficient (rearward)
L_{cgr} = Longitudinal distance from rear axle to (COG)

Tilt Test (lateral roll)

- Position vehicle on tilt table with each wheel on a load cell
- Quad bikes (quads) are to be tested such that the lateral COG of the unladen vehicle is offset towards the downhill tilt direction. Side by Side Vehicles (SSVs) are to be tested such that the driver position is offset towards the downhill direction
- Align vehicle such that a line passing through the outer edge of the two downhill tyres is parallel to the tilt axis of the table
- Set steering mechanism in the straight-ahead position
- Apply park brake to stop the vehicle from rolling
- Affix two catch straps (of less than 1kg) between vehicle and tilt table with slack to allow full decompression of high side suspension and minimal wheel lift
- Raise tilt table until both uphill tyres have lost contact with the ground (ie. both uphill load cells show no load)
- Return the tilt table to the horizontal position
- The Static Stability Factor (SSF) which is approximately equal to the static rollover threshold of vehicle in g's of lateral acceleration (1g = acceleration of gravity) is calculated as the Tangent of the tilt angle at wheel lift (Tan ∅)

Tilt Test (Pitch)

- Position vehicle on tilt table with each wheel on a load cell
- Vehicles are to be tested in both rearward pitch and forward pitch
- Align vehicle such that a line passing through the centreline of the contact patch of the two downhill tyres is parallel to the tilt axis of the table
- Set steering mechanism in the straight-ahead position
- Apply park brake, place the vehicle in gear and fix the wheel or brake assembly (if required) to stop the vehicle from rolling. If the low side vehicle tyres slip on the

load cells before wheel lift, place a ratchet strap over each low-side vehicle wheel and load cell such that the line of action of the strap passes through the contact patch of the tyre and the axle centreline, whilst still allowing the tyre to roll about the contact patch when the vehicle tips.
- Affix two catch straps (of less than 1kg) between vehicle and tilt table with slack to allow full decompression of high side suspension and minimal wheel lift
- Raise tilt table until both uphill tyres have lost contact with the ground (ie. both uphill load cells show no load).
- Return the tilt table to the horizontal position

Instruments
- Four load cells with at least 700kg load capacity and resolution of at least 0.5kg
- Tilt sensor with a range of at least 80° and a resolution of at least 0.1°
- Data acquisition system acquisition rate of at least 100 samples per second
- Real time filming (front 45° angle)

Appendix B
Test matrix

Appendix Prepared by: Drew Sherry

Appendix Checked by: Ross Dal Nevo

1. Test number matrix

				Roll					Pitch forward					Pitch rearward				
Vehicle make	Vehicle model	Crush Protection Device	Specimen number	No load	ATD	ATD+front load	ATD+front load+rear load	ATD+rear load	No load	ATD	ATD+front load	ATD+front load+rear load	ATD+rear load	No load	ATD	ATD+front load	ATD+front load+rear load	ATD+rear load
Honda	Fourtrax TRX250	N/A	TS57199	G130011	G130012	G130013	G130014	G130015	G130144	G130145	G130146	G130153	G130154	G130155	G130152	G130151	G130150	G130149
Honda	Foreman TRX500FM	N/A	TS57200	G130039	G130040	G130041	G130042	G130043	G130114	G130118	G130115	G130116	G130117	G130123	G130119	G130120	G130121	G130122
Yamaha	Grizzly YFM450FAP	N/A	TS57201	G130024	G130025	G130290	G130027	G130291	G130100	G130099	G130281	G130097	G130280	G130090	G130091	G130278	G130093	G130279
Polaris	Sportsman 450HO	N/A	TS57202	G130049	G130050	G130286	G130052	G130287	G130124	G130125	G130282	G130127	G130283	G130133	G130132	G130285	G130130	G130284
Suzuki	Kingquad 400ASI	N/A	TS57203	G130031	G130033	G130288	G130035	G130289	G130101	G130102	G130277	G130104	G130276	G130111	G130110	G130274	G130108	G130275
Kawasaki	KVF300	N/A	TS57204	G130016	G130017	G130018	G130019	G130020	G130166	G130167	G130168	G130169	G130170	G130175	G130174	G130173	G130172	G130171
Kymco	MXU300	N/A	TS57205	G130001	G130003	G130005	G130007	G130009	G130156	G130157	G130158	G130159	G130160	G130165	G130164	G130163	G130162	G130161
CF Moto	CF500	N/A	TS57206	G130044	G130045	G130046	G130047	G130048	G130134	G130135	G130136	G130137	G130138	G130143	G130142	G130141	G130140	G130139
Can-am	DS90X	N/A	TS57211	G130029	G130030	***	***	***	G130180	G130181	***	***	***	G130183	G130182	***	***	***
Yamaha	Raptor YFM250R	N/A	TS57212	G130022	G130023	***	***	***	G130176	G130177	***	***	***	G130179	G130178	***	***	***
Honda	TRX700XX	N/A	TS57213	G130037	G130038	***	***	***	G130089	G130088	***	***	***	G130086	G130087	***	***	***
Honda	Fourtrax TRX250	Quadbar	TS57199+CPD1	G130064	G130065	G130066	G130067	G130068	G130249	G130250	G130253	G130252	G130251	G130245	G130270	G130271	G130272	G130273
Honda	Fourtrax TRX250	Lifeguard	TS57199+CPD2	G130073	G130069	G130070	G130071	G130072	G130247	G130257	G130254	G130255	G130256	G130246	G130266	G130267	G130268	G130269
Honda	Fourtrax TRX250	Quickfix	TS57199+CPD3	G130297	G130298	G130299	G130300	G130301	G130248	G130258	G130259	G130260	G130261	G130244	G130265	G130264	G130263	G130262
Kymco	MXU300	Quadbar	TS57205+CPD1	G130074	G130075	G130076	G130077	G130078	G130184	G130185	G130186	G130187	G130188	G130193	G130192	G130191	G130190	G130189
Kymco	MXU300	Lifeguard	TS57205+CPD2	G130083	G130079	G130080	G130081	G130082	G130203	G130194	G130195	G130196	G130197	G130202	G130201	G130200	G130199	G130198
Kymco	MXU300	Quickfix	TS57205+CPD3	G130292	G130293	G130294	G130295	G130296	G130204	G130205	G130206	G130207	G130208	G130213	G130212	G130211	G130210	G130209
CF Moto	CF500	Quadbar	TS57206+CPD1	G130054	G130057	G130058	G130062	G130063	G130214	G130215	G130216	G130217	G130218	G130243	G130222	G130221	G130220	G130219
CF Moto	CF500	Lifeguard	TS57206+CPD2	G130055	G130056	G130059	G130084	G130085	G130239	G130235	G130238	G130237	G130236	G130242	G130223	G130224	G130225	G130226
CF Moto	CF500	Quickfix	TS57206+CPD3	G130302	G130303	G130304	G130305	G130306	G130240	G130234	G130231	G130232	G130233	G130241	G130227	G130230	G130229	G130228
Yamaha	Rhino YXR700	N/A	TS57207	G130307	G130308	***	***	G130309	G130331	G130332	***	***	G130333	G130336	G130335	***	***	G130334
Kubota	RTV500	N/A	TS57208	G130310	G130311	***	***	G130312	G130337	G130338	***	***	G130339	G130342	G130341	***	***	G130340
John Deere	Gator XUV825i	N/A	TS57209	G130316	G130317	***	***	G130318	G130319	G130320	***	***	G130321	G130324	G130322	***	***	G130323
Honda	Big Red MUV700	N/A	TS57210	G130313	G130314	***	***	G130315	G130325	G130326	***	***	G130327	G130330	G130329	***	***	G130328
Tomcar	TM-2	N/A	TS57620	G130350	G130351	***	***	G130352	G130349	G130344	***	***	G130345	G130348	G130347	***	***	G130346

*** Not tested in this configuration (no load rack)

Appendix C
Instrument Response Data

Intentionally not added to this report as file is large (356 pages)

Appendix D
Test specimen details

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

1. Vehicle details and specimen numbers

Make	Honda	Honda	Yamaha	Polaris	Suzuki	Kawasaki	Kymco	CF Moto	Can-am	Yamaha	Honda	Yamaha	Kubota	John Deere	Honda	Tomcar
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	TS57620
Vehicle type	ATV - agricultural	ATV - agricultural	ATV - agricultural	ATV - agricultural	ATV - agricultural	ATV - agricultural	ATV - agricultural	ATV - agricultural	ATV - Sport	ATV - Sport	ATV - 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
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
COG height (mm)	436	528	496	533	510	494	492	554	389	422	491	572	519	576	511	671
Stability coeff (Kst)	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8	1.2	1.0	1.0	1.0	1.0	1.1	1.3	1.1

2. Crush Protection Device (CPD) details

CPD device	Quadbar	Lifeguard	Quick-fix CPD
Manufacturer	QB Industries	Ag TECH industries	Quick-fix
CPD reference number	CPD1	CPD2	CPD3
Mass	8.5kg	14.8kg	30.0kg
Mounting location	Behind rear load rack & tow hitch	Rear load rack	Front load rack & rear load rack
Mounting method	Two U-bolts to rear load rack & tow ball bolt	Four J-bolts to rear load rack	Two U-bolts to front load rack & Two U-bolts to rear load rack


Quadbar


Lifeguard


Quick-fix

See Appendix E for more CPD device and fitment photographs.

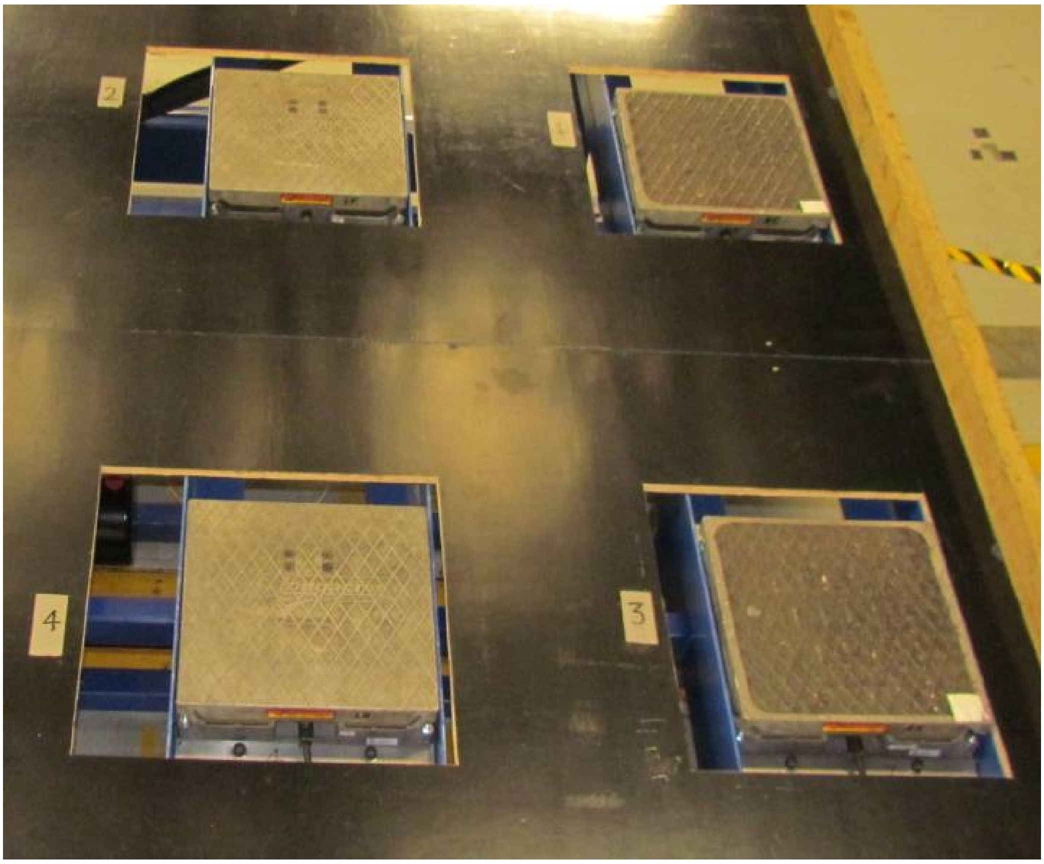
Appendix E
Test Photographs

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

1. Test equipment photographs

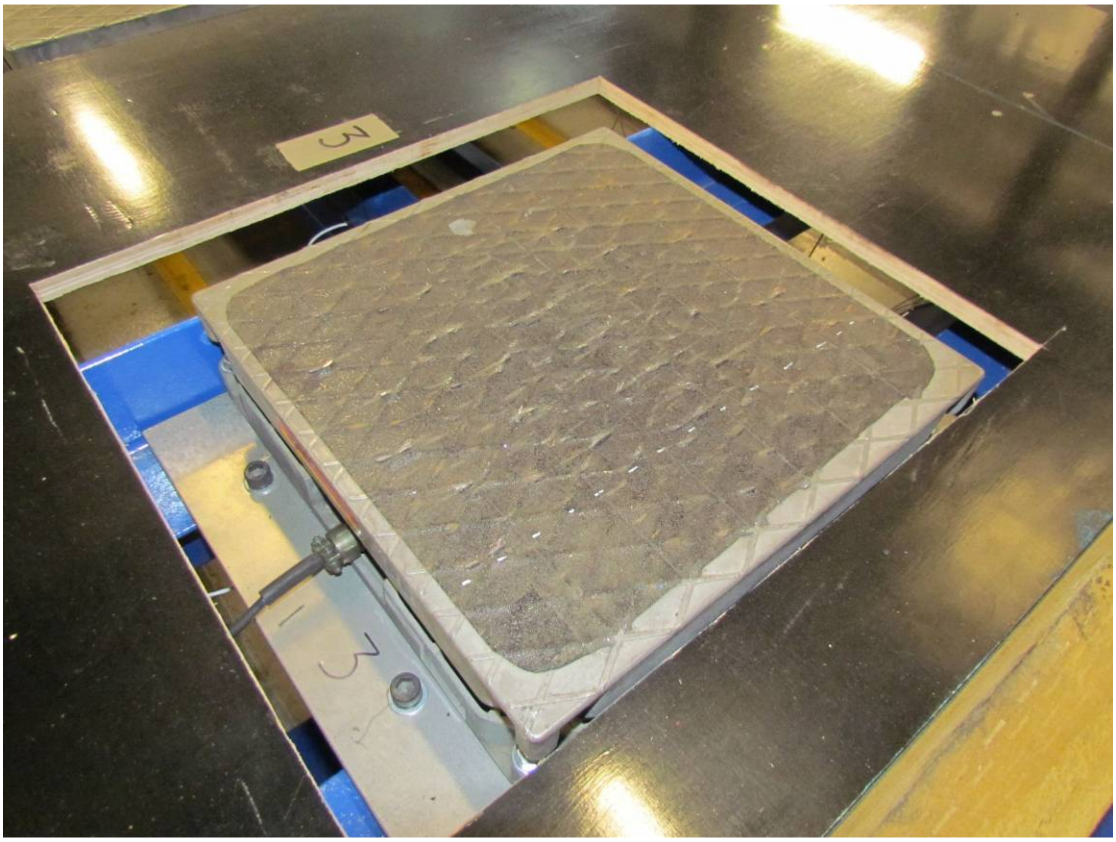
Tilt table (lowered, horizontal position)

Tilt table (partially raised position)

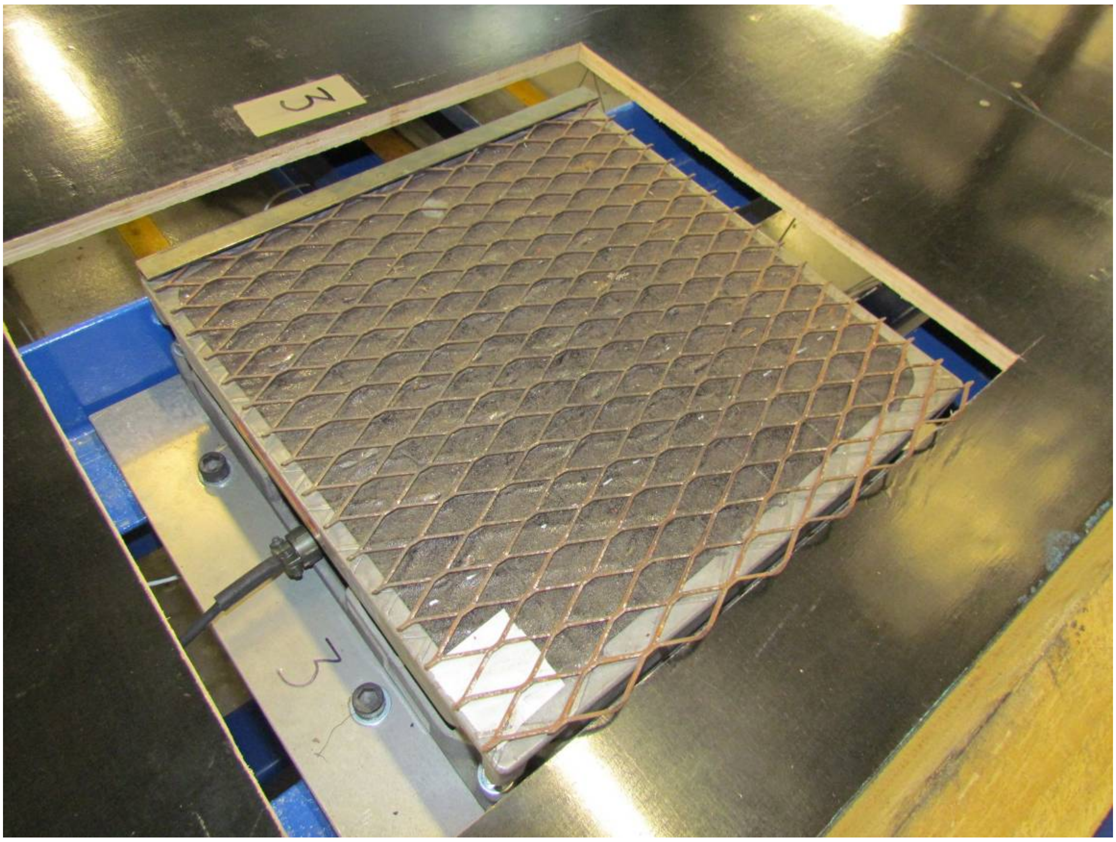


Tilt table load cells (load cell 2 and load cell 4 record the 'high side' wheels at lift off)

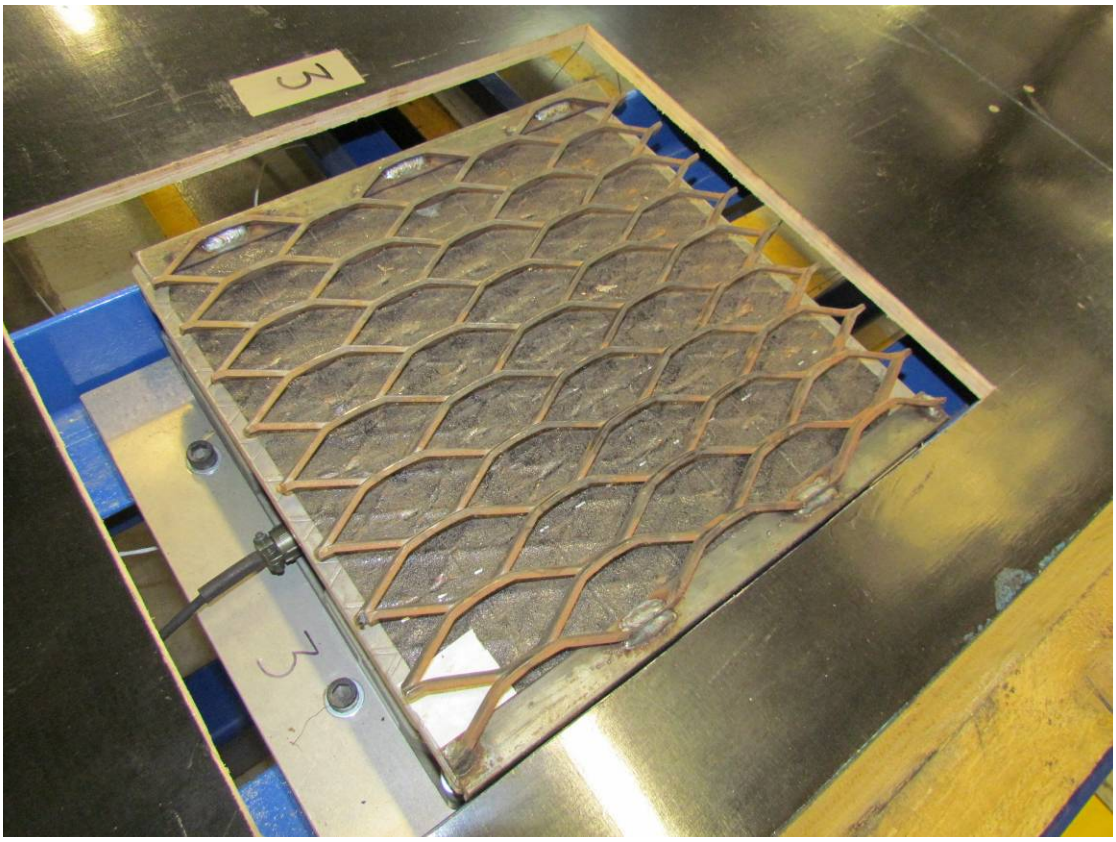
Tilt table tilt sensor, mounted to upper table frame



Load cell with high friction anti-slip tape surface



Load cell with fine expanded mesh anti-slip plate



Load cell with course expanded mesh anti-slip plate

2. 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)

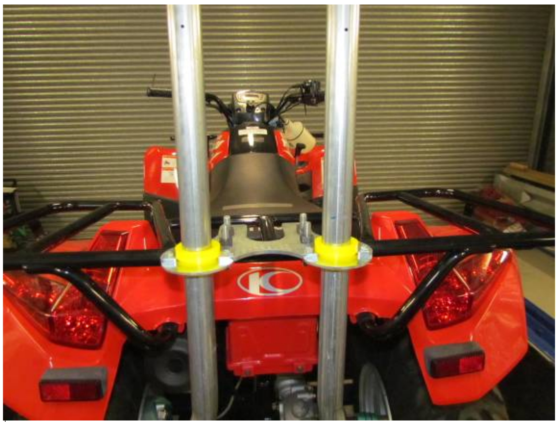
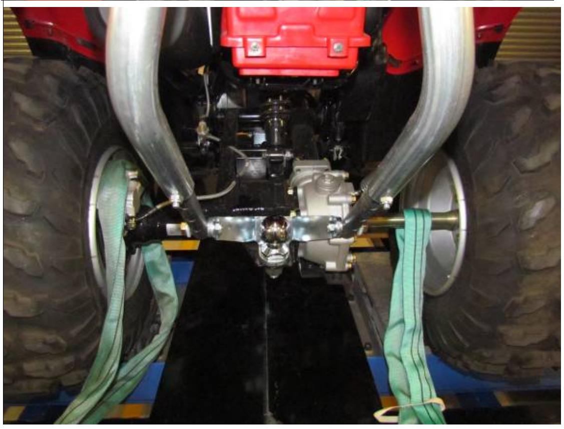
Honda Big Red MUV700 (TS57210)

Tomcar TM-2 (TS57620)

Tomcar TM-2 (TS57620)

3. Crush Protection Device (CPD) photographs


QB Industries Quadbar

Typical Quadbar installation

Ag-TECH Industries Lifeguard

Typical Lifeguard installation

Quick-fix crush protection device

Typical Quick-fix installation

4. Test setup photographs (ATV)

Typical ATV set up for lateral roll test (G130001)

Typical ATV set up for lateral roll test (G130001)

Typical ATV lateral roll test, vehicle liftoff (G130001)

Typical ATV lateral roll test, tyre squirm at vehicle liftoff (G130005)

Typical ATV set up for forward pitch test (G130156)

Typical ATV set up for forward pitch test (G130156)

Typical locking of ATV front brakes for forward pitch test (G130156)


Typical ATV forward pitch test, vehicle liftoff (G130156)

Typical ATV set up for rearward pitch test (G130165)

Typical ATV set up for rearward pitch test (G130165)

Typical locking of ATV rear brakes for rearward pitch test (G130165)

Typical ATV rearward pitch test, vehicle liftoff (G130165)

5. Test setup photographs (SSV)

Typical SSV set up for lateral roll test (G130316)

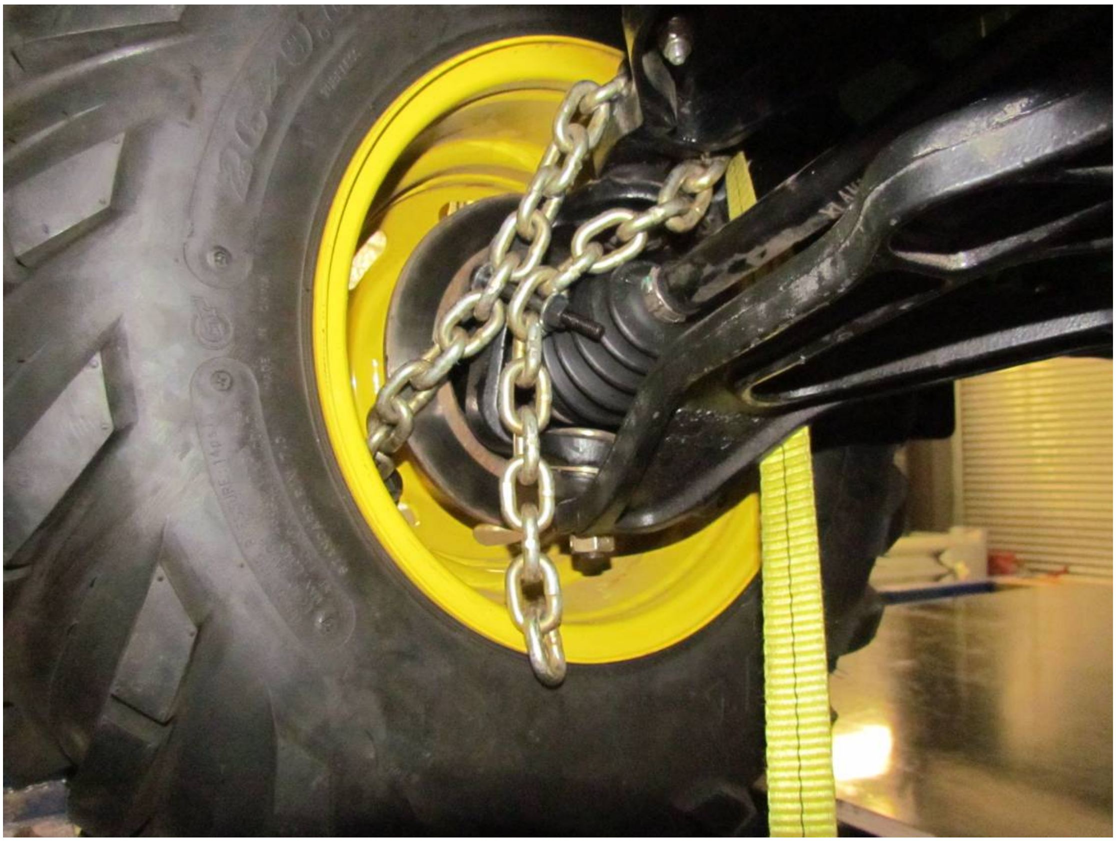
Typical SSV set up for lateral roll test (G130316)

Typical SSV lateral roll test, vehicle liftoff (G130316)

Typical ATV lateral roll test, tyre squirm at vehicle liftoff (G130316)

Typical SSV set up for forward pitch test (G130319)

Typical SSV set up for forward pitch test (G130319)



Typical locking of SSV front wheels for forward pitch test (G130319)

Typical vertical strapping of SSV front wheels to load cell for forward pitch test (G130319)

Typical SSV forward pitch test, vehicle liftoff (G130319)

Typical SSV set up for rearward pitch test (G130324)

Typical locking of SSV rear wheels for rearward pitch test (G130324)

Typical vertical strapping of SSV rear wheels to load cell for rearward pitch test (G130324)

Typical SSV rearward pitch test, vehicle liftoff (G130324)

6. Test setup photographs (load configurations)

Typical ATV setup - no load (G130001)

Typical ATV setup – with Hybrid III 95%ile ATD (G130003)

Typical ATV setup - with ATD and front load (G130005)

Typical ATV setup - front load fastening, load distributed on cargo rack

Typical ATV setup - with ATD and rear load (G130009)


Typical ATV setup - rear load fastening, load distributed on cargo rack

Typical ATV setup - with ATD, front load and rear load (G130007)

Typical SSV setup - no load (G130319)

Typical SSV setup - with Hybrid III 95%ile ATD (G130320)

Typical ATV setup - with ATD and rear load (G130321)

Typical SSV setup - rear load fastening, load distributed in utility tray

Appendix F
Instrument details

Appendix Prepared by: Drew Sherry

Appendix Checked by: Ross Dal Nevo

1. Instrument details

Instrument	Manufacturer	Model	Serial number	Instrument number	Position	Calibration date	Resolution	Non-linearity
Tilt sensor	Rieker	N4C-5	48528	T0620	Table tilt	07-January-2013	0.01degrees	0.2%FS
Load cell	Longacre	Computerscales 92	TCL7	T1700	Position 2	04-February-2013	0.03kg	0.2%FS
Load cell	Longacre	Computerscales 92	TCL7	T1701	Position 4	04-February-2013	0.03kg	0.2%FS
Load cell	Longacre	Computerscales 92	TCL7	T1702	Position 1	04-February-2013	0.03kg	0.2%FS
Load cell	Longacre	Computerscales 92	TCL7	T1703	Position 3	04-February-2013	0.03kg	0.2%FS