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An assessment of passive roll over protection for Quad Bikes

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Purpose
The Faculty of Engineering and Surveying Technical Reports serve as a mechanism for disseminating results from certain of its research and development activities. The scope of reports in this series includes (but is not restricted to): literature reviews, designs, analyses, scientific and technical findings, commissioned research, and descriptions of software and hardware produced by staff of the Faculty of Engineering and Surveying.

Abstract

Roll over protection is an important factor in improving the safety of ATV's (Quad bikes). A test apparatus and test procedure have been proposed to test the effectiveness of a system to arrest the potential for harm during back flip or sideways roll over of a quad bike during normal use. This test procedure was assessed to determine the reliability of the test rig to control the linear and angular momentum of the vehicle at the point of roll. The "Quad Bar" is one product that has been proposed to counter the risks associated with such roll overs. Roll over behaviour of two typical ATV's was tested with and without the Quad Bar product fitted and the effectiveness of the Quad Bar system is demonstrated.

1 Introduction

This paper reports a recent evaluation carried out by the University of Southern Queensland, Toowoomba Queensland Australia. The project was funded by QB Industries with a request to evaluate (a) the effectiveness of the "Vehicle Accelerator" test apparatus in controlling the conditions at the point of sideways roll and backwards flip of a four wheel all terrain vehicle (ATV) on inclined terrain; and (b) the effectiveness of the "Quad Bar" passive roll over protection device in arresting the roll of an ATV or in controlling the roll to reduce the likelihood of a user being trapped under the ATV.

2 Context of the Investigation

Safety concerns related to ATV usage have become widespread as the demand and popularity of these vehicles has increased over the past decade. In the current investigation the primary focus is on incidents where the vehicles are used sensibly by trained personnel, particularly whilst conducting regular farm and other "in the field" activities.

An "active rider" is assumed whereby the rider sits astride the seat and uses their body mass and inertia to influence the behaviour of the ATV. During a roll over sequence the rider is assumed to be loosely de-coupled from the vehicle (that is, the rider mass and inertia have a minimal effect on the vehicle dynamics).

Two particular accident scenarios were considered and tested:

- Side roll over on horizontal and sloping ground; and
- Back flip that would typically occur whilst accelerating up an incline or upon braking whilst rolling backwards down an incline.

Events prior to the point of roll over are not considered relevant in the present study. Thus, an apparatus has been developed that consistently places the ATV at the point of roll with linear and angular momentum commensurate with those experienced in an actual roll over event.

Two ATV's were selected for testing that were deemed to be representative of those commonly used in the wider community in a farm setting:

- Yamaha Moto 4 250cc (mass of 249 kg)
- ODES Cattleman EX400 series 4x2 (mass of 254 kg)

All testing was done under "in the field" conditions. Environmental and all test conditions were recorded to ensure direct comparison testing was appropriate between test sequences.

3 General Test Method

The "Vehicle Accelerator"

A test apparatus (Figure 1), herein referred to as the Vehicle Accelerator, was developed that would allow the ATV to accelerate in a given direction and orientation to provide sufficient kinetic energy to initiate a roll, either sideways or in back flip. The ATV rests on a sled which is positioned on an inclined ramp and the controlling variables are sled sliding distance and inclination angle. The ATV wheels rest against a side stop, which helps initiate a roll.

On commencement of testing, the sled (and ATV) are released and slide down the incline. At the end of this travel, a small kick-bar is positioned that guides the top roller on the sled to impart angular speed to the sled (and ATV). Thus, some of the linear momentum of the sled and ATV is converted to angular momentum just at the point of release (see figure 2). The average speed of the sled and ATV are determined just prior to reaching this kick-bar by a timer and two proximity sensors at a 500mm spacing.

Observations of the ATV behaviour during the roll (see figure 3), during ground contact and of final rest position were made for each test sequence.

Figure 1. Vehicle Accelerator

Further details of the Linear Accelerator test apparatus are contained in Appendix A.

Figure 2. ATV at point of roll

Figure 3. ATV during sideways roll sequence

Test Procedure

The general test procedure was:

1. Determine an appropriate test site with the ground surface free from debris or surface irregularity. At all times the ground surface was dry with uniform soil compaction.
2. Position the Vehicle Accelerator and adjust levels.
3. Position the sled surface to horizontal and mount the riderless ATV under consideration.
4. Use the hydraulic ram to raise the inclined surface to the desired angle and adjust the kick-bar position.
5. Release the sled (and ATV).
6. Record the average speed of the sled and ATV just prior to roll initiation.
7. Observe the ATV release and subsequent motion during the roll sequence. Motion video was recorded of every roll sequence.
8. Record the ground contact and final rest position of the ATV.
9. Examine the ground impact site and the ATV for damage prior to subsequent testing.

In selected tests, a 1 tonne HBM S40 load cell (S/N 30375657) was mounted on the top of the Quad Bar hoop so that lateral force and longitudinal force could be measured when ground contact occurred in side rolls and back flips. In all tests the ATV handle bars and instrument cluster were replaced by more durable and replaceable surrogates with equivalent mass and stiffness.

Preliminary Testing

A series of tests were performed using the Yamaha Moto 4 250 ATV to determine the overall behaviour of the Vehicle Accelerator apparatus and to assess the repeatability of the test results.

Five tests were conducted with a sled inclination of 22.5° and a sled length of 3m running onto a horizontal ground surface. The ATV speed just prior to release was found to be consistent with a mean speed of 9.163km/hr with a standard deviation of 0.033km/hr.

The motion of the ATV during roll showed consistent behaviour and end rest position for all five tests. The video evidence was analysed to allow comparison of the linear and angular velocities of the ATV just after release and these were also consistent between runs. Whilst it is an interesting academic exercise to evaluate the linear and angular momentum of the ATV during the roll motion, it was not considered further in the present study where the initial test conditions and the final rest position of the ATV are of relevance.

This preliminary test series provided confidence that the Vehicle Accelerator apparatus could be used to provide controlled roll behaviour of an ATV so that direct comparison could made between different vehicle configurations. The sled/ATV speed was recorded for all further testing and used as a check that the test configuration was correct. A variation in mean speed of greater than 1% was deemed to be an indicator of problems with the test setup and warranted further investigation.

The Quad Bar device

The Quad Bar (figure 4) is a passive roll over protection device for ATV's that has been developed by QB Industries. A batch of such Quad Bars were provided for testing on the Yamaha Moto 4 250cc and the ODES Cattleman Ex400 series 4x2 ATV's. Further details on the Quad Bar product are contained in Appendix B.

Figure 4. The Quad Bar product mounted on an ATV

The Quad Bars as supplied for testing were each comprised of an aluminium tube which was mounted on the tow bar and was telescopically adjustable at the base so that the top of the hoop is at an appropriate height relative to the head of the rider. A foam protective cover was installed over the hoop. A support mount is attached to the rear rack, where the bar passes through sliding collars (bushes), which subsequently allow the suspension to move freely. It was apparent that the use of the tow bar would not be adversely affected by the attachment of the Quad Bar.

QB Industries provided technical staff who worked under the direction of the Chief Investigator for this project in the fitting and removal of the Quad Bars as appropriate.

4 Results

Results of the test series are detailed in the tables below. In each case, the initial test conditions are listed along with the name of the video data file for that test. This is followed by a brief description of the roll behaviour followed by the final rest position of the ATV.

Yamaha Moto 4 250 in sideways roll onto horizontal surface

Table 1 shows at lower speeds (5.9-6.6 km/hr) the unprotected ATV final rest position is upside down in close proximity to the roll point (figure 5), where the rider may become trapped beneath the vehicle. As speed increases (7.7-8.6 km/hr) the ATV tends to complete a three quarter roll and its rest position is on its opposite side (figure 6).

Table 1. Yamaha Moto 4 250cc sideways roll onto horizontal surface

2.00m incline at 23° (5.191 km/hr) [MVI_1665]	ATV completes half roll	Upside down (figure 5)
2.25m incline at 23° (6.608 km/hr) [MVI_1666]	ATV completes half roll	Upside down
2.25m incline at 23° (6.584 km/hr) [MVI_1667]	ATV completes half roll	Upside down
2.25m incline at 23° (6.581 km/hr) [MVI_1668]	ATV completes three quarter roll but then rolls back	Upside down
2.50m incline at 23° (7.727 km/hr) [MVI_1669]	ATV completes three quarter roll	On opposite side
2.50m incline at 23° (7.700 km/hr) [MVI_1670]	ATV completes three quarter roll	On opposite side (figure 6)
2.75m incline at 23° (8.613 km/hr) [MVI_1671]	ATV completes three quarter roll	On opposite side
2.75m incline at 23° (8.617 km/hr) [MVI_1672]	ATV completes three quarter roll	On opposite side

Figure 5. Test 1665 with ATV upside down after half roll

Figure 6. Test 1670 with ATV on opposite side after three quarter roll

Yamaha Moto 4 250 in sideways roll onto horizontal surface – with Quad Bar

The high speed (8.6 km/hr) sideways roll over test was then repeated with the Quad Bar device fitted to the Yamaha quad bike. Test 1673 arrested the roll with the ATV resting on its side adjacent to the roll point. Test 1675 completed a three quarter roll with the ATV resting on its opposite side. During the roll, there was a clear space between the ATV seat section and the ground in both cases (figure 7). These results are summarised in table 2.

Table 2. Yamaha Moto 4 250cc sideways roll onto horizontal surface with Quad Bar fitted

2.75m incline at 23° (8.583 km/hr) [MVI_1673]	ATV completes half roll (figure 7)	On side (figure 8)
2.75m incline at 23° (8.581 km/hr) [MVI_1675]	ATV completes three quarter roll	On opposite side

Figure 7. Test 1673 with ATV inverted part way through the roll sequence (with large space between the seat and the ground surface)

Figure 8. Test 1673 with ATV resting on side at the end of the roll sequence

Table 3 shows results of sideways roll over tests onto horizontal ground at slightly lower speeds (7.6 km/hr) and in all these cases the Quad Bar device arrested the roll over of the ATV.

Table 3. Yamaha Moto 4 250cc sideways roll onto horizontal surface with Quad Bar fitted

2.50m incline at 23° (7.633 km/hr) [MVI_1676]	Roll is arrested just prior to half roll	On side
2.50m incline at 23° (7.636 km/hr) [MVI_1677]	Roll is arrested just prior to half roll	On side
2.25m incline at 23° (6.527 km/hr) [MVI_1678]	Partial roll	On side
2.00m incline at 23° (5.239 km/hr) [MVI_1679]	Partial roll	On side

The 1 tonne load cell was then attached to the top section of the Quad Bar hoop and configured to record the maximum lateral force experienced by the hoop during a roll over sequence. A maximum speed of 9.3 km/hr was induced. Two tests were conducted (1680 and 1681). The maximum lateral force experienced during roll onto horizontal ground was F = 1255 Newtons.

Table 4. Yamaha Moto 4 250cc sideways roll onto horizontal surface with Quad Bar fitted

3.00m incline at 23° (9.301 km/hr) [MVI_1680]	Three quarter roll	On side F_{max} = 1225N lateral
3.00m incline at 23° (9.232 km/hr) [MVI_1681]	Three quarter roll	On side F_{max} = 1255N lateral

Yamaha Moto 4 250 in sideways roll onto sloping surface – with Quad Bar

The Vehicle Accelerator was then repositioned so that the ground surface at the end of the test sled was sloping at a rate of 20°. The Vehicle Accelerator was levelled and the sled incline was set at 26°. The test sequence commenced with the Yamaha Moto 4 250 with the Quad Bar fitted.

These results indicate there is a greater tendency for the ATV to continue to roll compared to tests onto horizontal ground at the same speed. This is to be expected. In cases where the ATV completed more than one full roll, the final rest position was not reported because the rider would be very likely to have become separated from the vehicle during the accident.

Table 5. Yamaha Moto 4 250 in sideways roll onto sloping surface with Quad Bar fitted

3.00m incline at 26° (10.137km/hr) [MVI_1682]	ATV completes two roll overs	Not applicable F_{max} = 1368N lateral
2.25m incline at 26° (7.085 km/hr) [MVI_1683]	ATV completes one full roll with some skidding	Not applicable
2.25m incline at 26° (7.074 km/hr) [MVI_1684]	ATV completes one full roll	Not applicable
2.00m incline at 26° (5.639 km/hr) [MVI_1685]	Roll is arrested just prior to half roll	On side
2.00m incline at 23° (5.379 km/hr) [MVI_1686]	Roll is arrested just prior to half roll	On side
2.00m incline at 23° (5.415 km/hr) [MVI_1687]	Roll is arrested just prior to half roll	On side

A minor discrepancy appeared in the average speed measurements after test 1685. After investigation it was noted that there was a minor hydraulic oil leak in the test apparatus. This was repaired and testing continued with a sled inclination angle of 23°.

Yamaha Moto 4 250 in sideways roll onto sloping surface

As shown in table 5, rolls initiated by an average speed of 5.4 km/hr were demonstrably arrested by the Quad Bar device with the ATV resting on its side. This test configuration was then repeated with the Quad Bar removed and these results (shown in table 6) are significant. At this speed the Quad Bar device prevents the roll over of the ATV.

Table 6. Yamaha Moto 4 250cc sideways roll onto sloping surface

2.00m incline at 23° (5.420 km/hr) [MVI_1688]	Two full rolls	Not applicable
1.60m incline at 23° (unknown) [MVI_1689]	Two full rolls	Not applicable

Yamaha Moto 4 250 in back flip onto sloping surface – with Quad Bar

The Vehicle Accelerator was then relocated so that the ground surface at the end of the test sled was sloping at a rate of 20°. The Vehicle Accelerator was levelled and the sled incline was set at 24°. The adjustable stops were repositioned on the sled so that the ATV could be oriented facing up the incline. The test sequence commenced with the Yamaha Moto 4 250 with the Quad Bar fitted.

Table 7. Yamaha Moto 4 250cc back flip onto sloping surface with Quad Bar

2.00m incline at 24° (4.357 km/hr) [MVI_1725 video lost]	ATV stands on hoop and falls to left. Does not roll over.	On side
2.00m incline at 24° (4.344 km/hr) [MVI_1726 video lost]	ATV stands on hoop and falls to right. Does not roll over.	On side
2.00m incline at 24° (4.299 km/hr) [MVI_1727]	ATV stands on hoop and falls to right. Does not roll over (See figure 9)	On side

Figure 9. Moto 250 at highest point during potential back flip

Yamaha Moto 4 250 in back flip onto sloping surface

The back flip tests were then repeated for the Yamaha Moto 4 250 with the Quad Bar removed. Tests were conducted at the same average speed of 4.3 km/hr and at the same ground slope and sled inclination. The results (table 8) were most dramatic with the Quad Bike rolling over completely and resting upside down (figure 10) in a position where the rider would certainly be trapped if they had not been thrown clear during the roll.

Table 8. Yamaha Moto 4 250cc back flip onto sloping surface with Quad Bar

2.00m incline at 24° (4.299 km/hr) [MVI_1728]	ATV rolls over backwards.	Upside down (figure 10)
2.00m incline at 24° (4.353 km/hr) [MVI_1729]	ATV rolls over backwards.	Upside down
2.00m incline at 24° (4.284 km/hr) [MVI_1730]	ATV rolls over backwards.	Upside down

Figure 10. Moto 250 at rest after low speed back flip – without Quad Bar

ODES Cattleman EX400 in back flip onto sloping surface – with Quad Bar

The back flip tests were then repeated for the ODES Cattleman EX400 4x2 with the Quad Bar fitted. Tests were conducted within the same general speed range and at the same ground slope and sled inclination. The regular increments of sled position were adjusted in these tests and so only the average sled/ATV speed is reported in table 9. The results indicate that the Quad Bar prevents the quad bike from flipping over backwards and instead causes the vehicle to fall to one side.

Table 9. ODES Cattleman EX400 back flip onto sloping surface with Quad Bar

Incline at 24° (4.194 km/hr) [MVI_1731]	ATV stands on hoop and falls to right. Does not roll over.	On side
Incline at 24° (4.172 km/hr) [MVI_1732]	Brakes failed and ATV wheeled down incline.	Not applicable
Incline at 24° (4.189 km/hr) [MVI_1733]	ATV stands on hoop and falls to right. Does not roll over.	On side

ODES Cattleman EX400 in back flip onto sloping surface

The Quad Bar was then removed and the back flip test was repeated for the ODES Cattleman EX400 at the same incline and sled speed. In this test, the quad bike wheeled approximately 400mm before the back flip continued. It was found that the brakes on this vehicle were not fully engaged. Nonetheless, the back flip did occur and results were dramatic as shown in video test 1734.

Table 10. ODES Cattleman EX400 back flip onto sloping surface

Incline at 24° (4.148 km/hr) [MVI_1734]	400mm wheel and then back flip with multiple subsequent rolls.	Not applicable

ODES Cattleman EX400 in sideways roll onto sloping surface – with Quad Bar

The Vehicle Accelerator was then adjusted so that sideways roll over tests (to the left) could be conducted on the ODES Cattleman EX400. These tests produced unexpected results (table 11). Under all test conditions, if the quad bike reached the roll point during its motion, it then continued to roll unimpeded down the remainder of the incline. Considerable damage was occurring to the mud guards and steering column and some deep grooves were found in the ground surface where the steering column was first impacting. This required relocation of the test apparatus and or smoothing and compaction of the ground surface for subsequent tests.

Table 11. ODES Cattleman EX400 sideways roll onto sloping surface with Quad Bar

Incline at 24° (4.591 km/hr) [MVI_1735]	ATV just rolls over, but once it does, the ATV continues to roll down the incline.	Not applicable
Incline at 24° (5.173 km/hr) [MVI_1736]	ATV rolls over, and then continues to roll down the incline.	Not applicable
Incline at 24° (4.579 km/hr) [MVI_1737]	ATV rolls over, and then continues to roll down the incline.	Not applicable
Incline at 24° (4.568 km/hr) [MVI_1738]	ATV rolls over, and then continues to roll down the incline.	Not applicable

In order to achieve results where the quad bike may possible rest in an unsafe "upside down" position, adjustments were made to the sled incline so that lower average sled speeds were possible. These tests were from heights that precluded the use of the speed transducer and so average sled speed has been estimated on the basis of video evidence. These results are shown in table 12.

Table 12. ODES Cattleman EX400 sideways roll onto sloping surface with Quad Bar

Incline at 12° (3.8 km/hr) [MVI_1741]	ATV rolls over, and then continues to roll down the incline.	Not applicable
Incline at 12° (3.5 km/hr) [MVI_1742]	ATV just rolls over, and then continues to roll down the incline.	Not applicable

ODES Cattleman EX400 in sideways roll onto sloping surface

The sideways roll test was then repeated with the ODES Cattleman EX400 with the Quad Bar removed. In this test (1743) the quad bike continues to roll down the incline.

Table 13. ODES Cattleman EX400 sideways roll onto sloping surface

Incline at 12° (3.5 km/hr) [MVI_1743]	ATV just rolls over, and then continues to roll down the incline.	Not applicable

ODES Cattleman EX400 in sideways roll onto horizontal surface

The final tests conducted were to investigate sideways roll of the ODES Cattleman EX400 onto a horizontal surface. The Vehicle Accelerator was repositioned and levelled, and the sled inclination was set at 21.5°. Table 14 shows the results of the first test where the quad bike was tested without the roll over protection in place. A low average sled speed was chosen for this test.

Table 14. ODES Cattleman EX400 sideways roll onto sloping surface

Incline at 21.5° (4.696 km/hr) [MVI_1745]	ATV slowly rolls onto its back.	Upside down (figure 11)

Figure 11. Test 1745 with Cattleman ATV resting upside down at the end of the roll sequence

ODES Cattleman EX400 in sideways roll onto horizontal surface – with Quad Bar

Table 15 shows the results of the test where the quad bike was tested with the roll over protection fitted. The same average sled speed (4.6 km/hr) was used as for test 1745.

Table 15. ODES Cattleman EX400 sideways roll onto sloping surface

Incline at 21.5° (4.642 km/hr) [MVI_1746]	ATV rolls onto its side.	On side

Figure 12. Test 1746 with Cattleman ATV resting on side at the end of the roll sequence

5 Discussion

A number of important factors and observations can be drawn from the results provided in this report.

The Vehicle Accelerator

1. The Vehicle Accelerator apparatus is a reliable means of inducing the linear and angular momentum necessary to induce roll over in an ATV.
2. The Vehicle Accelerator provides repeatable average sled and ATV speeds (within 1%) under a range of conditions.
3. The Vehicle Accelerator allows the operator to remain a safe distance from the roll of the ATV.

The roll over behaviour of quad bikes

1. At low speeds on horizontal ground, there is a strong tendency for quad bikes to roll over sideways to an upside down position. If the rider is not thrown clear of the ATV during the roll over then there is a high probability that the rider will be trapped under the vehicle and will be at risk of crushing or asphyxiation.
2. At low speeds on sloping ground there remains a possibility of the quad bike resting in an upside down position.
3. A safe and cautious rider is unlikely to be operating at elevated speeds in a work situation. Roll over can still occur due to unbalance or uneven terrain and so the risks associated with these low speed roll overs are significant.
4. As ATV speed increases, the likelihood of the ATV remaining upside down decreases. However, at times during the roll there is little clearance between the ATV and the ground and the potential for serious injury remains high.

5. The square body shape of quad bikes such as the Yamaha Moto 4 250 makes them more likely to rest upside down in low speed sideways roll over. The more rounded body and flexible bodywork of quad bikes such as the ODES Cattleman EX400 gives these a strong tendency to continue to roll once initiated.
6. Low speed back flip of an ATV on sloping ground demonstrates a tendency to leave the ATV in an upside down condition, with the concomitant risk of trapping the rider.

The Quad Bar device

1. The Quad Bar did not impede rider operation of the quad bike during normal operation (based on limited riding by the Chief Investigator).
2. In low speed sideways roll over, the Quad Bar arrests the roll over and prevents the ATV from resting in a position that could trap and asphyxiate the rider.
3. In higher speed sideways rollover, the Quad Bar impedes the roll over and prevents the ATV from resting in a position that could trap and asphyxiate the rider. In all tests the Quad Bar provided some clearance between the ground surface and the ATV seat so the rider would be unlikely to be trapped in this space.
4. In all back flip tests, the Quad Bar arrested the back flip and the quad bike fell to one side.
5. There were no conditions where the ATV with the Quad Bar fitted rested in a position that was more detrimental to rider safety than the ATV without protection.

6 Conclusions and Recommendations

The Vehicle Accelerator is appropriate for use in testing roll over behaviour of ATVs and should be considered in any Standard Test Procedures that may be developed in the future.

The Quad Bar passive roll over protection device is effective in reducing the likelihood of rider injury in ATV sideways roll over and back flip and should be considered an essential safety feature of ATVs in the workplace and recreational environment.

Appendix A

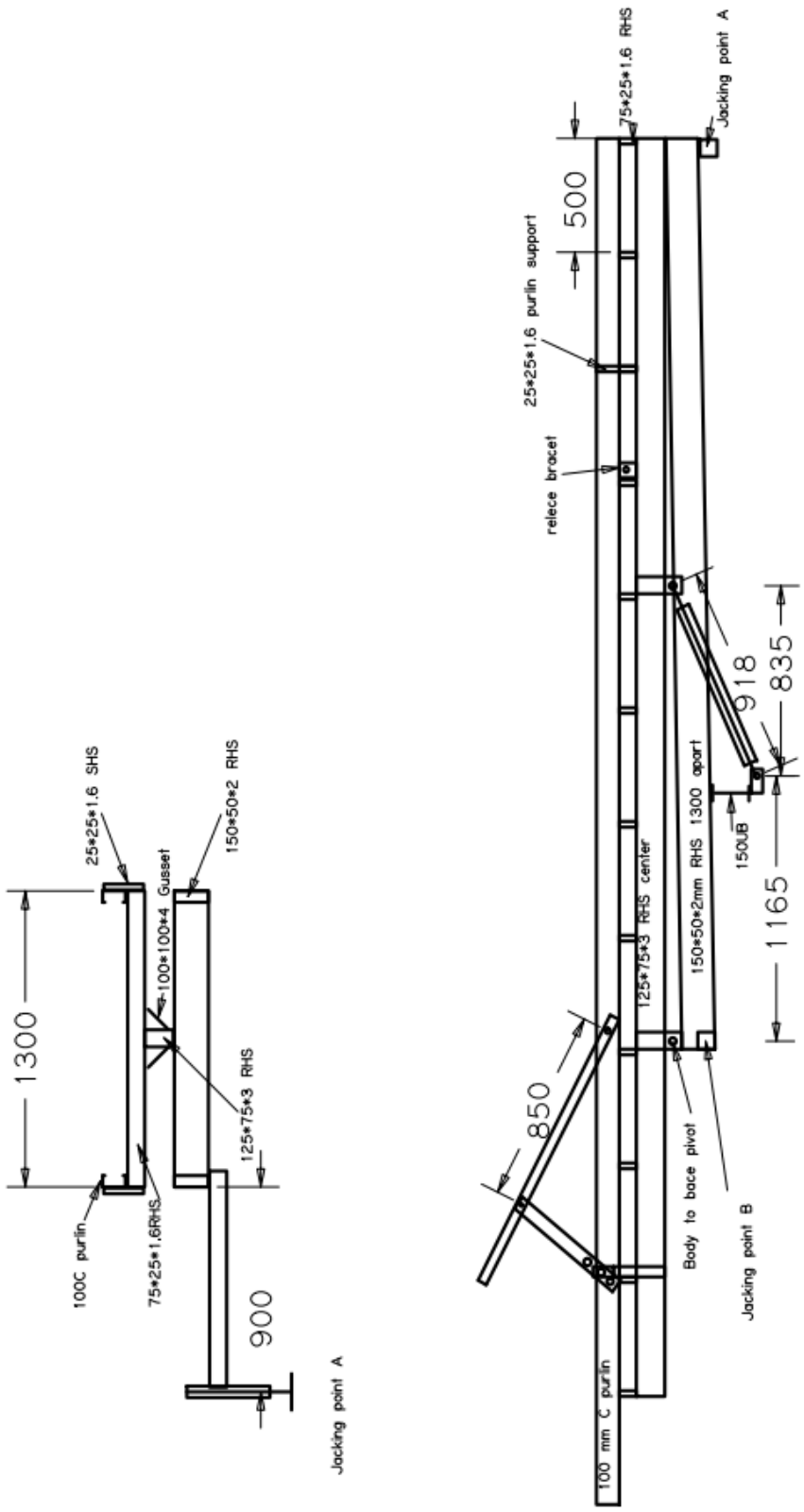

Figure 13. Vehicle Accelerator in horizontal position

Appendix B

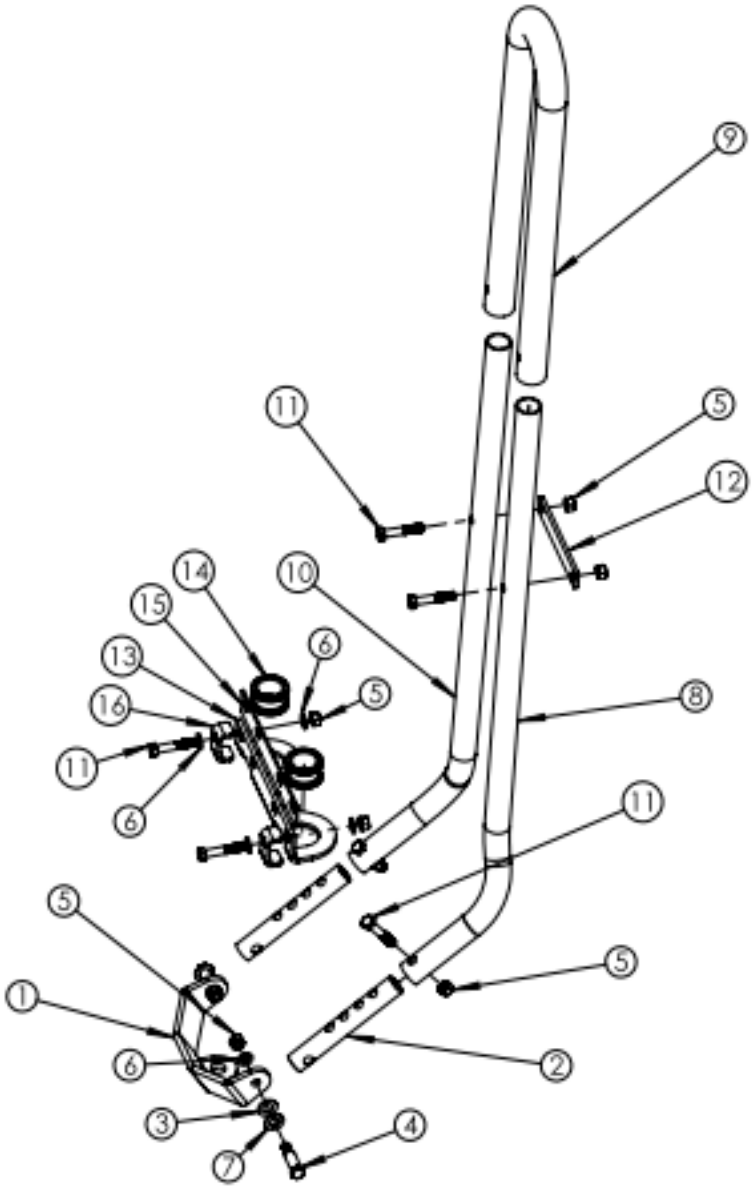

Figure 14. The Quad Bar

Appendix C

Attached to this report is a DVD which contains the video files referred to in tables 1-15. All files are a standard AVI format and can be viewed by any standard video software including Microsoft Media Player or Apple Quicktime software.