DEVELOPMENT OF PROPOSED DYNAMIC CRASH TESTS AND PERFORMANCE CRITERIA FOR THE AUSTRALIAN CONCESSION GO-KARTS STANDARD

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Paper Number 17-0157

ABSTRACT

Go-karting is a popular recreational motor sport in Australia and many other countries. Go-karts are small, motorised vehicles that are capable of relatively high speeds. Because of their small size, go-karts present unique crashworthiness challenges to their designers (not unlike micro automobiles and quadricycles). The small distances involved result in limited opportunity for ride-down decelerations of crash forces in frontal and other crash involvements. The international commercial and racing go-karting industry continues to recommend the rider be unbelted, so they can eject from the go-kart during a crash. Hence, the European Commission's EN 16230 standard specifying go-kart into go-kart crashworthiness tests only requires an effective velocity change (delta V) of 7 km/h claiming higher test speeds are impractical.

This study demonstrates that a crashworthy go-kart for higher impact speeds with the rider restrained with a 3-point belt is possible. A practical dynamic crashworthiness performance functional test for commercial hire go-karts and associated track barrier and other infrastructure systems was developed. The results of this research are being considered as a crashworthiness test requirement in a revision of the Australian Standard for concession go-karting and associated track infrastructure safety.

The crash test described in this paper were developed based on results from reconstructions of two fatal go-kart crashes reported elsewhere. For each fatality, a MADYMO model was developed to represent the driver, go-kart and barrier system. Alternative barrier designs and seat belt configurations were then modelled. Based on results of those fatal crash reconstructions and modelling of different barrier and restraint scenarios, it was demonstrated that requiring riders to wear seat belts and carrying out crash tests at higher speeds was practical and would improve go-kart crashworthiness. Subsequently, a series of crash tests were devised in conjunction with industry representatives, that would be demonstrative of typical crash scenarios in a concession based go-kart environment. Go-kart into go-kart impacts were conducted in frontal and nose-tail at 50 km/h based on European test configurations at the New South Wales state government Crashlab facility near Sydney in Australia. Tests were also conducted on a range of barrier designs. Two impact configurations were tested: one at 25 km/h at a 90 degree impact angle and one at 50 km/h at 25 degree impact angle.

The results of modelling of fatal crashes as well as crash testing into different barrier configurations and vehicle to vehicle testing has proven high energy crashes (crashes at the track design top speed) involving go-karts on concession tracks can be made survivable with the use of appropriate restraint systems in the vehicle and effective barriers designed for likely impacts. The study outcomes have revealed that the European Commission (2016) EN 16230 standard frontal impact test should be set at a much higher impact speed, encouraging improvements to be made to occupant protection and crash barriers systems for go-karts used in that jurisdiction.

INTRODUCTION

Go-karting is a popular recreational motor sport in Australia and many other countries (Commission Internationale de Karting, 2017). Go-karts are small, motorised vehicles that are capable of relatively high speeds. Because of their small size, go-karts present unique crashworthiness challenges to their designers (not unlike micro automobiles and quadricycles). The small distances involved result in limited opportunity for ride-down decelerations of crash forces in frontal and other

crash involvements such as into barriers or infrastructure hard points.
Investigation of Australian fatality and injury data between 2000 – 2007 (Grzebieta, Mitchell and Zou, 2014) identified there had been around 10 go-kart related deaths in Australia in that period, or more than one per year. Half of these (5) occurred at commercial race tracks and four at off-site locations. One death was subject to a Coroner's Inquest at the time (Grzebieta et al, 2014). Grzebieta et al (2014) also found there were around 37 hospital admissions across Australia each year for the period 2002/03 to 2009/10. A US study (Collins et al, 2007) showed go-kart injuries constituted approximately 13.7% of around 1.2 million non-automobile motorised vehicle related injuries that presented at emergency departments (ED) between 1990 – 2003.

The international commercial and racing go-karting industry continues to recommend the rider be unbelted, so they can eject from the go-kart during a crash. Hence, the European Commission (2016) EN 16230 standard that specifies go-kart into go-kart crashworthiness tests only requires an effective velocity change (delta V or ΔV) of 7 km/h claiming higher test speeds are impractical. The standard does not specify any tests into barriers that redirect the go-kart.

This position, recommending the rider be unbelted, is contrary to the principles of vehicle occupant protection first espoused in the widely acclaimed work *Accident Survival – Airplane and Passenger Automobiles* by De Haven in 1952. De Haven related occupant protection in vehicles to the packaging principles used in the transport industry. In simple terms, De Haven's four principles are:

(a) *The vehicle occupant compartment should contain its occupants (no ejection) and should not collapse under reasonable or expected conditions of force.*

(b) *The materials that surround and shield the occupant compartment should be capable of resisting crash forces by yielding and absorbing energy.*

(c) *Vehicle occupants should be restrained within the occupant compartment to prevent the second collision (injurious impact with the interior of the occupant compartment).*

(d) *Padding must be provided for parts of the occupant compartment that the occupant might strike.*

De Haven's principles remain as directly relevant to vehicle safety today as they were in 1952 and apply equally to go-karts as for any other vehicle types.
The objectives of this study were to demonstrate that a crashworthy go-kart rated at a higher delta V impact speed with the rider restrained with a 3-point belt is possible, and to develop practical functional dynamic crashworthiness performance tests for commercial hire go-karts and associated track barriers and other infrastructure systems trackside.

The results of this research are being considered in the current revision of the Australian Standard AS 3533.4.4-2011 (Standards Australia, 2011) as a possible crashworthiness performance requirement for go-karts and track barrier safety.

METHODS AND DATA SOURCES

Two fatal go-kart crashes were reconstructed by Grzebieta et al. (2013, 2014). The first involved a crash that occurred at an organised street racing event called the Wollongong City Kart Prix in Australia (Grzebieta et al., 2013). The go-kart track was lined with empty plastic barriers that would otherwise be filled with water for ballast in order to redirect an errant vehicle in traffic conditions at roadworks. After crossing the finish line, the go-kart impacted the barriers at a speed estimated to be in excess of 100 km/h. The driver was flung from the kart head first into the barrier and received fatal spinal and other injuries. The fatality was reconstructed using computer simulation. A MADYMO model was developed to represent the driver, go-kart and barrier system. A second model was constructed where the driver was properly restrained and the barrier was redesigned to have a smooth interface and heavier than the empty KI 1000 barriers. The smooth barrier was capable of safely redirecting the go-kart such that it travelled parallel to the barrier after impact and the seat belts restrained the rider from being thrown forward. The rider would have likely survived the crash.

A reconstruction of a second fatal crash involving a helmeted and four-point harness seat belted small female rider who suffered a basilar skull fracture was also undertaken (Grzebieta, et al., 2014). The fatal crash occurred at a speed of 25 km/h and an impact angle of 90 degrees into the concrete barrier of a hire go-kart track that was lined with a single row of unconnected car tyres. The reconstruction again included use of MADYMO computer simulation models to determine how a four-point harnessed occupant could receive the fatal injury.

Investigation of the effectiveness of a single tyre against a concrete wall barrier for crash energy absorption was undertaken. A Baldwin universal compression-testing machine was used to determine the load deformation characteristics of the tyre compressed across its diameter. This load deformation curve produced was then used to simulate the interaction between the go-kart and the barrier.

Two different barrier scenarios were then modelled. The first scenario employed tyres joined together laterally and placed 0.5 metres in front of the concrete wall. The second scenario employed two tyres placed in series in front of the wall. A fourth scenario was modelled, adding a crotch strap fifth point of attachment to the safety harness to stop harness “ride up”.

Based on results of the crash reconstructions and modelling of different scenarios, a series of crash tests were developed, in conjunction with industry partner committee members helping revise the Australian Standard AS 3533.4.4-2011 for go-karts and associated track infrastructure safety. Both go-kart into go-kart tests and go-kart into barrier tests were devised that would be representative of typical higher energy crash scenarios and test configurations that the EN 16230 standard requires in a concession based go-kart environment. The objective of the tests was a proof of concept that crash tests could be carried out, that practical results could be obtained and that the crashworthiness of go-karts and barriers could be improved at these higher ΔV values. These dynamic tests were undertaken at the New South Wales (NSW) State Government Roads and Maritime Services Agency’s Crashlab test facility.

A survey of Australian kart operators identified a common maximum speed for indoor karts at 45 km/h and outdoor karts at 70 km/h. Hence, a design speed for concession tracks was chosen as 50 km/h. The striking (bullet) go-kart travelling at 50 km/h impacting the stationary target go-kart of the same model and mass, results in a ΔV = 25 km/h. For barrier impacts, angled impacts (25 degrees) were conducted at 50 km/h. This is equivalent to a striking impact velocity of 21 km/h perpendicular into the barrier. For this reason, the impact speed for perpendicular impacts (90 degrees) was set at 25 km/h.

The test vehicle used for all crash tests was a RiMO EVO6 go-kart supplied by RiMO Australia being representative of the current generation of go-kart fleets in Australia. Kingston Park Raceway supplied all the barriers.

The Crashlab tow system was used to propel the striking go-kart up to the either required impact test speeds of 25 km/r and 50 km/h. The tow cable was released just prior to impact. Instruments to measure three axis of linear and rotational acceleration were fitted at the go-kart’s centre of gravity. A data acquisition system, emergency remote control braking system and a power supply (battery) were also fitted to the kart. To maintain the original in-service vehicle mass and weight distribution it was necessary to remove the engine in the strike vehicle to accommodate the Crashlab test equipment. The impacted (target) go-kart was the same go-kart with no alterations and same mass.

All vehicles used in testing had a 50^{th} percentile Hybrid III Anthropomorphic Test Device (ATD) with a nominal mass of 78kg fitted. The 50th percentile Hybrid III represents the average sized adult male and is the most widely used and commonly available crash test dummy in the Hybrid III ATD family. The advantage of using the Hybrid III 50^{th} ATD in providing the required occupant ballast is that it also simulates the occupant’s likely kinematic response (dynamic movement) in a real world crash during impact.

The first set of tests carried out were the go-kart into go-kart tests. Test 1 is a head on collision set up as shown in Figure 1 based on the European test configuration (European Commission, 2016). The striking go-kart travels at 50 km/h and impacts the stationary go-kart nose to nose such that the two longitudinal axes of the go-karts are aligned. Because the two go-karts have the same mass the change in velocity experienced by the ATD in either go-kart will be half the striking go-kart’s speed, i.e. ΔV = 25 km/h.

A second go-kart into go-kart test was also carried out albeit the configuration was such that the striking go-kart hits the rear of the stationary go-kart that was again the same make and mass as the striking go-kart as shown in Figure 2. Again, the test configuration was based on the European test (European Commission, 2016) the change in velocity both ATDs experienced was 25 km/h.

As mentioned earlier, tests were also conducted on a range of barrier design options at 25 km/h at 90 degree impact angle and 50 km/h at 25 degree impact angle. The test matrix for the barrier test sequence is shown at Table 2.

A video recording at 500 frames per second 50 ms just prior to impact and until the end of the crash event was taken. An overhead and side view that clearly showed the striking vehicle and object struck through the whole crash event and until the striking vehicle and objects struck (either go-kart or barrier) came to rest, was recorded.

Photographs of the test configurations that include images of the respective vehicles and barriers from overhead, side, forward and rear views before and after testing were also recorded and documented.

The deceleration in the longitudinal and lateral directions within the go-kart's horizontal plane was measured and recorded. The accelerometers were attached to an appropriate fixture that was located on the go-kart's longitudinal centreline as close as practicable to the go-kart's centre of gravity in the test configuration, i.e. vehicle combined with instrumentation and ATD. The accelerometers mounting fixture are directly fixed to the go-kart's main chassis frame in such a manner so as to ensure that any decelerations measured were of the frame and not of any other part that moves relative to the frame during the crash test.

For each crash test configuration specified, deceleration of the striking go-kart and acceleration of the struck go-kart was sampled at a frequency of 10 kHz and processed using a CFC180 filter. The velocity of the go-kart was also recorded just before impact.

EVALUATION CRITERIA

The evaluation of the go-kart into go-kart tests and each barrier's crash test performance included observations and assessment of the risk to the go-kart rider, and in the case of the barrier tests the barrier's structural adequacy, and the trajectory of the vehicle. The criteria commonly used to assess road safety barriers in the United States (US) Recommended Procedures for the Safety Performance Evaluation of Highway Features (Ross et al., 1993) based on the Flail Space model (Tan et al., 2017) was adapted to both the go-kart into go-kart tests and the go-kart into barrier tests. This is described in more detail as:

Structural Adequacy
Detached elements, fragments or other debris during impact from either the go-kart or the safety barrier should not present an undue hazard to the driver, to other go-kart drivers or track personnel operating the facility.

Occupant Risk.
The two measures of occupant injury based on acceptable Occupant Impact Velocity and Ride-down Acceleration as shown in Table 2 and Table 3 respectively.

Table 1.
Occupant Impact Velocity for barrier testing

Occupant Impact Velocity	Preferred (m/sec)	Max. (m/sec)
Longitudinal (V_x)	9	12
Lateral (V_y)	+/-9	+/-12

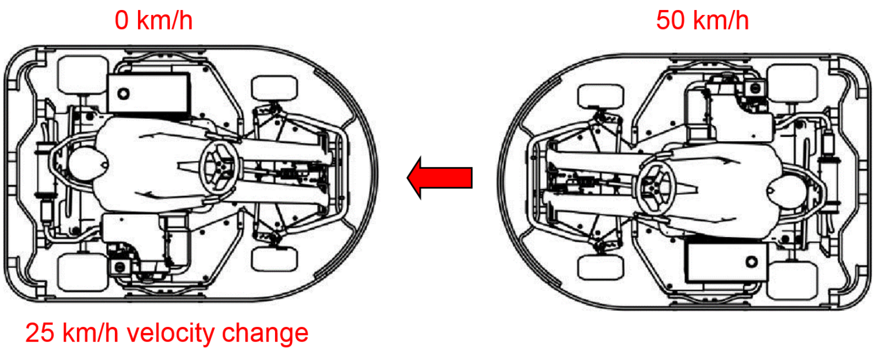


Figure 1. Test 1: Head-on impact conducted at 50 km/h into a stationary target vehicle

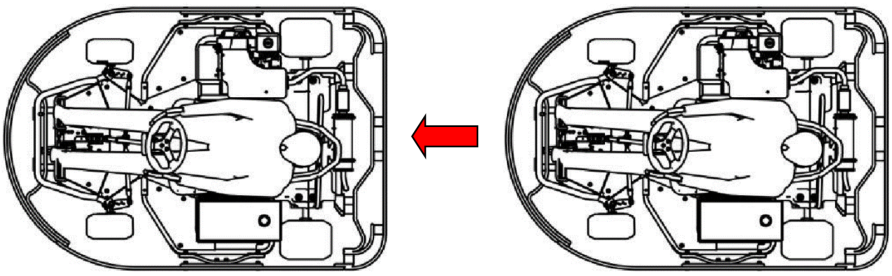


Figure 2. Test 2: Rear impact Rear impact test conducted at 50 km/h into stationary target vehicle

Table 2.
Barrier Test Matrix

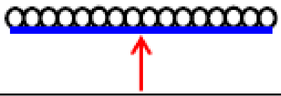
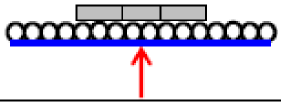
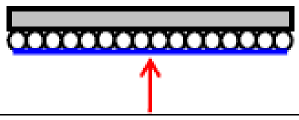
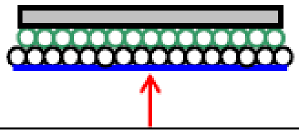
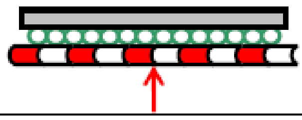
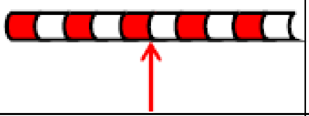
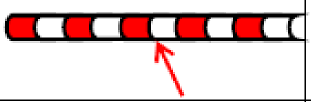
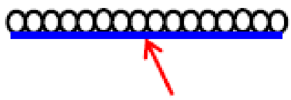
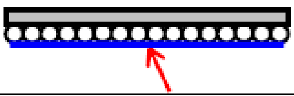
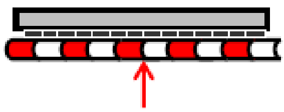
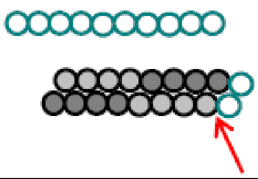
Run #	Vel Km/h	Impact Angle (0°)	Barrier Configuration	Description
B14012	25	90		Tyre wall 16 tyres long, 2 tyres high, bolted together, with a conveyor belt bolted on front face.
B14013	25	90		Same as test B14012, with bolted tyre wall (16 x 2) with conveyor belt front, back against concrete jersey barriers.
B14014	25	90		Repeat of B14013, with bolted tyre wall (16 x 2) with conveyor belt front, back against a rigid concrete wall.
B14015	25	90		Tyre wall 16 tyres long, 2 tyres high, with convey belt front separated from rigid concrete wall by row of double height loose tyres.
B14016	25	90		Plastic barrier, 10 segments long connected together with 35 kg of water ballast in each. Separated from rigid concrete wall by row of double height loose tyres.
B14017	25	90		Plastic barrier wall, 10 segments long connected together with 35 kg of water ballast in each. Perpendicular impact at connection of barriers in centre of wall.
B14018	50	25		Plastic barriers, 10 segments long connected with 35 kg of water ballast in each. Angled impact on barrier connection at centre of wall.
B14019	50	25		Tyre wall 16 tyres long, 2 tyres high, bolted together with a conveyor belt on front face. Angled impact at centre of wall between junction of tyres.
B14020	50	25		Same as B14020, with tyre barrier against concrete wall.
B14021	50	25		Plastic Barriers, as per B14017, with barrier separated from concrete wall by single row of loose standing tyres.
B14022	50	25		Bolted tyre segments, 4 tyres long and 2 tyres high. Double depth wall formed by overlapping 4 segments (not connected). Row of loose single tyres placed 2M behind and parallel to barrier. Angled impact at leading edge of non-connected segments.

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Table 3:
Acceptable Occupant Ride-down Accelerations for barrier testing

Ride-down Acceleration	Preferred (g's)	Max. (g's)

Longitudinal (G_x)	-15	-20
Lateral (G_y)	+/-15	+/-20

The Occupant Impact Velocity is the velocity at which a hypothetical, unrestrained occupant would impact a hypothetical vehicle interior surface. Ride-down acceleration is determined as the 10 millisecond average deceleration a hypothetical, unrestrained occupant would experience when impacting a hypothetical vehicle interior surface, i.e. flailing and striking the steering wheel in the case of a go-kart.

Go-kart Into Go-Kart Performance Criteria
For the go-kart into go-kart crash tests the following criteria were established:

- In accordance with Table 2, the driver impact velocity must be less than 12 m/s (43 km/h) but preferably 9 m/s (32 km/h) or less;
- In accordance with Table 2, the average ride down deceleration must be less than 20 g's but preferably 15 g's or less;
- Driver's head in both the striking and the struck go-kart should not contact the steering wheel.
- The go-kart should remain upright during and after collision although moderate roll, pitching and yawing are acceptable;
- The go-kart should not penetrate into, under-ride, or over-ride the struck go-kart such that it presents a hazard to the rider of the striking vehicle or the struck vehicle;
- Controlled deformation of either go-kart's bumper system is acceptable so long as any deformation or fracture does not present a hazard to either driver or track personnel operating the facility;
- Detached elements, fragments or other debris during impact from either go-kart should not present an undue hazard to either driver or track personnel operating the facility;

Go-kart Into Barrier Performance Criteria

For the go-kart into barrier crash tests the following criteria were established:

- In accordance with Table 2, the driver impact velocity must be less than 12 m/s (43 km/h) but preferably 9 m/s (32 km/h) or less;
- In accordance with Table 2, the average ride down deceleration must be less than 20 g's but preferably 15 g's or less;
- The striking go-kart's exit angle from the safety barrier preferably should be less than 15 degrees, measured at time of the go-kart's loss of contact with the safety barrier;
- The go-kart should not penetrate through, under-ride, or override the safety barrier although controlled lateral deflection (working width) of the safety barrier is acceptable.
- The go-kart preferably should not snag or be pocketed in the case of an angled 25 degree impact by the barrier during impact;
- The go-kart should remain upright during and after collision although moderate roll, pitching and yawing are acceptable;

RESULTS
The head on impact (B14007) and the rear impact (B14008) test results are respectively shown in Appendix A. For both head-on and rear impact tests the Occupant Impact Velocity and the Ride-down Acceleration were within limits of the injury criteria based on the flail space model. However, for the head-on impact in both the striking (bullet) go-kart and struck (target) go-kart the helmet on the ATD contacted the steering wheel. On closer observation of the high speed videos, it was clear that excessive real out of the sash part of the belt in combined with the deflection of the go-kart's roll bar to which the sash guide was attached, led to the helmet contacting the steering wheel. It was proposed that stiffening the roll bar and using webbing clamps to reduce belt real out would help prevent this contact.

The test results B14012 to B14022 for the go-kart into barrier crash tests are also respectively shown in Appendix A. For all barrier tests, the Occupant Impact Velocity and the Ride-down Acceleration were also within limits of the injury criteria based on the flail space model. However, in tests B14013, B14014, B14015, B14016, B14019 and B14020 the ATD's helmet made contact with the steering wheel. There was no damage to the vehicle or barrier in tests B14012, B14013, B14014, B14015, B14016, and B14017.

However, of particular concern with the go-kart into barrier tests was test B14019. The go-kart was not redirected by the barrier but instead continued forward and under-rode the barrier. This resulted in the barrier impacting the ATD in the chest and head. The steering wheel was bent backwards by the force. This impact would have been particularly hazardous for a rider.

A similar under-ride situation was observed is Test B14020. The go-kart commenced to under-run the barrier on impact without any redirection until it pocketed and then began to rotate in a clockwise direction. The steering wheel was forced to turn hard right and was struck by the Hybrid III's helmeted head.

DISCUSSION AND LIMITATIONS

The results of modelling of fatal crashes as well as crash testing go-kart into go-kart impacts and go-kart into different barrier configurations has proven higher energy crashes than those adopted in the EN 16230 standard (European Commission, 2016) involving go-karts on concession tracks are practical and offer increased crashworthiness with the use of appropriate restraint systems in the vehicle and effective barriers designed for likely impacts. Had the go-karts and barriers undergone such testing in the case of the two fatalities investigated by Grzebieta et al. (2013, 2014) both deceased riders would have survived the crash, highly likely without serious injury.

Ride down accelerations have been demonstrated to be able to be kept below injurious levels (less than 9 m/s) and occupant injury values less than 15 g through use of a 3 point seat belt and appropriate barrier design.

Go-kart Into Go-kart Tests.

The results of the go-kart into go-kart impact crash testing showed Occupant Impact Velocity and Ride-down Accelerations were within tolerable limits, but head strike against an unpadded steel steering wheel remained problematic. Use of a helmet complying with Australian and New Zealand Standard 1698: *Protective Helmets for Vehicle Users*, as well as using a deformable steering wheel rim and padded steering hub can assist with mitigating this injury risk. However, use of a 3 point belt with a webbing clamp and a stiffened roll bar where the sash is either anchored or guided, would sufficiently restrain the rider's torso so that head strike does not occur. Alternatively, improved seat belt configuration (correctly adjusted 5 point restraint with a crotch strap) was shown by modelling to minimise the risk of head strike in crashes (Grzebieta et al., 2014).

Go-kart into Barrier Tests:

The results of go-kart into barrier crash testing showed Occupant Impact Velocity and Ride-down Accelerations were also within tolerable limits, but head strike against an unpadded steering wheel was also problematic in a number of those impacts. In two cases the go-kart under-rode the barrier.
Key issues detected among the go-kart into various barrier tests conducted were:

- Two storey tyre configurations tended to allow under-ride of the barrier, even with a conveyor belt front piece fitted. Continuous smooth facia plastic barriers should be used to control and redirect an errant go-kart;

- Sufficient dynamic working width distance (movement during impact) behind the barrier is required to allow the barriers to effectively absorb crash energy through control movement without under-ride; and

- Tyre barriers fitted against a solid concrete wall resulted in head strike against the steering wheel. The implication here is where available track design space does not permit a large dynamic working width distance for the barrier to operate, then go-karts fitted with 3 point restraint systems need to have webbing clamps with a properly stiffened roll bar through which the sash part of the belt is fed. Alternative, a 5 point seat belt harness can be fitted but these belts must be correctly adjusted to a snug fit to minimise occupant movement relative to the vehicle.

General Comments

The study outcomes have revealed that the EN 16230 standard frontal and rear impact test (European Commission, 2016) should be set at a much higher delta V, encouraging improvements to be made to occupant protection systems for go-karts used in that jurisdiction. The EN 16230 standard should also include go-kart into barrier crash tests.

The results of this research are being considered for possible inclusion into the revised Australian Standard for go-kart and associated track infrastructure safety (Australian Standard 3533.4.4 *Amusement Rides and Devices - Go Karts*).

The data and results contained in this paper relate only to the specific vehicle and safety barriers tested. The vehicle tested was a used vehicle supplied as being suitable for the purpose of conducting go-kart barrier tests. The method by which safety barriers and components are assembled and the conditions under which they are installed may vary the performance results.

CONCLUSIONS

Simulations and crash tests revealed that it is possible to reduce injury risk for much higher impact speeds involving go-karts than is currently considered appropriate by the international commercial and racing go-karting industry. This study also proves it is possible to develop a practical and realistic dynamic crashworthiness performance test for commercially manufactured go-karts.

This paper has focussed on the research related to the safety performance of a go-kart that is subject to the same deceleration distance challenges as the micro and sub-compact cars, in terms of restraint and crashworthiness in a frontal crash with a special emphasis of restraint design pertaining to the rider. Wider application of these results may be possible for example in the go-kart racing environment with additional research.

ACKNOWLEDGEMENTS

The Authors would like to thank the technical staff at the NSW Roads and Maritime Services Crashlab facility for preparing and carrying out the crash tests. The Authors would also like to thank Mr. Terry Skene and staff at the Kingston Park Raceway in Queensland, Australia for assisting with preparation and supply of the barriers funded by their organisation and for providing advice and feedback from go-kart track owners. The support of the Chair of the Australian Standards Committee revising the Australian Standard for go-karts Ms Anthea Hammond from Scenic World, Katoomba in NSW, Australia, is also gratefully acknowledged.

Funding is always critical to the success of any safety related project. The bulk of the funding for testing was provided by The Australian Amusement, Leisure and Recreation Association Inc. (AALARA) with contributions from other track owners interested in the test results, for which the Authors are most grateful. RiMO Rental Karts Australia are also gratefully acknowledged for supplying the go-karts for testing.

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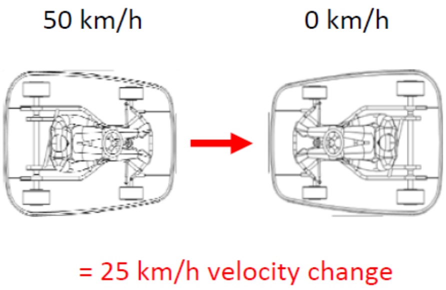
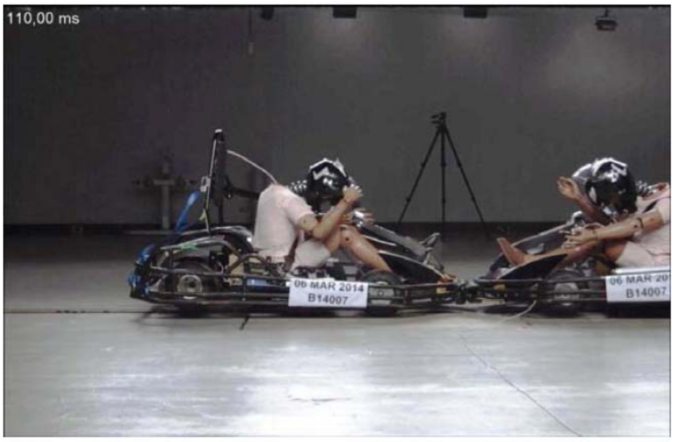
APPENDIX

The following results have been extracted from the NSW Roads and Maritime Services Crashlab TEST Report No BR2014/012 Go Kart Crash Barrier Tests, Project No: S/07509 authored by Dal Nevo R. and Lai A. for the client TARS UNSW.

Crashlab Test Number: B14007 Summary of Results Test Date: 6 March, 2014





Bullet vehicle damage:

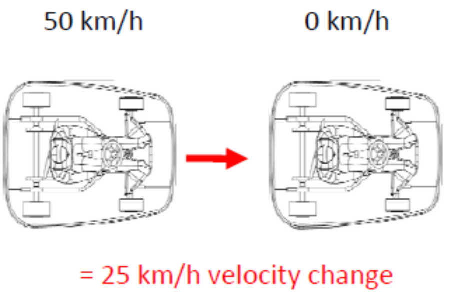
- Front RHS bumper bracket (steel) bent & fractured.
- Rear bumper guide tube displaced.
- Helmet contact with steering wheel at top of visor opening.
- Visor opened and detached during impact.

Target vehicle damage:

- Front RHS & LHS bumper brackets bent.
- Helmet contact with steering wheel at top of visor opening.
- Visor detached during impact.

Test Vehicle	Bullet	Target		
Vehicle model	Rimo EVO 6	Rimo EVO 68		
Designation	#8 ID: 071312724	#68 ID: 061312731		
Test mass (incl. ATD)	233.5kg	230.0kg		
Impact speed	50.0km/h	0 km/h		
Occupant Impact Velocity			*Preferred*	*Maximum*
Longitudinal (Vx)	**8.3**	**7.9**	*9*	*12*
Lateral (Vy)	**-0.1**	**0.3**	*+/-9*	*+/-12*
'Occupant impact' time	0.093s	0.100s		
Ridedown Acceleration			*Preferred*	*Maximum*
Longitudinal (Gx)	**-3.0**	**-1.7**	*-15*	*-20*
Lateral (Gy)	**-4.2**	**-2.6**	*+/-15*	*+/-20*
Maximum Cof Gx (g)	-34.6g @ 19.8ms	-32.6g @ 29.3ms		
Maximum Cof Gy (g)	-8.8g @ 112.9ms	-13.2g @ 58.6ms		
Maximum Cof Gz (g)	-34.4g @ 110.0ms	-27.1g @ 61.1ms		
Maximum roll angle	-2.1deg @ 334.9ms	deg @ ms		
Maximum pitch angle	-6.4deg @ 214.8ms	10.2deg @ 226.3ms		
Maximum yaw angle	-0.7deg @ 62.2ms	1.0deg @ 49.4ms		

<u>**Crashlab Test Number: B14008**</u> <u>**Summary of Results**</u> <u>**Test Date: 6 March, 2014**</u>



<u>Bullet vehicle damage</u>:

- Front RHS bumper bracket (steel) bent & (aluminium) fractured.
- Front LHS bumper bracket (steel) bent.
- Both rear bumper guide tubes dislodged.
- Helmet contacted steering wheel at top of visor opening and chin bar at steering wheel rim and hub.

<u>Target vehicle damage</u>:

- Rear bumper bent 20mm and both mounting brackets bent.
- No helmet contact with steering.

Test Vehicle	Bullet	Target		
Vehicle model	Rimo EVO 6	Rimo EVO 68		
Designation	#8 ID: 071312724	#68 ID: 061312731		
Test mass (incl. ATD)	233.5kg	230.0kg		
Impact speed	50.0km/h	0 km/h		
Occupant Impact Velocity			*Preferred*	*Maximum*
Longitudinal (Vx)	**8.2**	**-8.7**	*9*	*12*
Lateral (Vy)	**0.0**	**-0.8**	*+/-9*	*+/-12*
'Occupant impact' time	0.092s	0.439s		
Ridedown Acceleration			*Preferred*	*Maximum*
Longitudinal (Gx)	**-2.7**	**2.5**	*-15*	*-20*
Lateral (Gy)	**-3.6**	**6.2**	*+/-15*	*+/-20*
Maximum Cof Gx (g)	-39.9g @ 19.0ms	40.8g @ 16.9ms		
Maximum Cof Gy (g)	-14.8g @ 36.1ms	8.1g @ 69.3ms		
Maximum Cof Gz (g)	-31.1g @ 28.1ms	19.2g @ 66.4ms		
Maximum roll angle	3.1deg @ 160.0ms	-1.6deg @ 107.8ms		
Maximum pitch angle	-7.2deg @ 236.8ms	-17.7deg @ 299.1ms		
Maximum yaw angle	0.4deg @ 722.7ms	deg @ ms		

Crashlab Test Number: B14012 **Summary of Results** **Test Date: 24 March, 2014**

Test article	Bolted tyre wall, 16 long x 2 high, with
	conveyor belt front face.
Installation length	10.1 m
Height of barrier	Nominal 420 mm (400mm to 440mm)
Material	Passenger car tyres, nom. 205 x 65R x 15"
Weight of barrier	378 Kg (32 x9kg/tyre + 90kg conveyor)
Installation	Free standing on painted steel and
	concrete floor φ = 0.4
Test vehicle	Rimo EVO 6 Go Kart
Designation	#8 ID: 071312724
Test mass (incl. ATD)	225.5kg
Impact speed	25.2 km/h
Impact angle	90 degrees
Exit speed	
Exit angle	

Occupant Impact Velocity	Actual	*Preferred*	*Maximum*
Longitudinal (Vx)	**3.3**	*9*	*12*
Lateral (Vy)	**0.0**	*+/-9*	*+/-12*
'Occupant impact' time	0.259 s		
Ridedown Acceleration	Actual	*Preferred*	*Maximum*
Longitudinal (Gx)	**-0.9**	*-15*	*-20*
Lateral (Gy)	**-0.2**	*+/-15*	*+/-20*
Permanent barrier deflection	x-direction	2.735m	
Maximum Cof Gx (g)	-6.9g @ 28.1ms		
Maximum Cof Gy (g)	0.8g @ 59.4ms		
Maximum Cof Gz (g)	2.7g @ 9.8ms		
Maximum roll angle	0.1deg @ 166.9ms		
Maximum pitch angle	-0.4deg @ 50.7ms		
Maximum yaw angle	-0.6deg @ 399.4ms		

Observations:
No damage to vehicle or barrier. Vehicle pocketed at point of impact and penetrated into barrier 2.735 meters with no rebound.

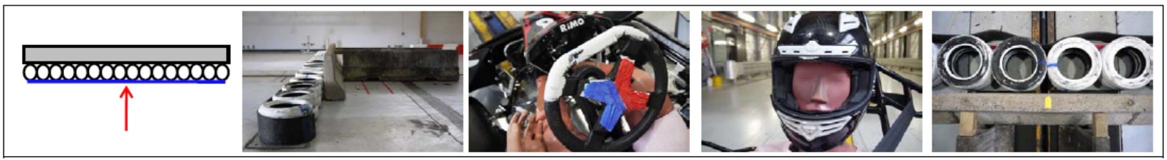
Crashlab Test Number: B14013 **Summary of Results** **Test Date: 24 March, 2014**

Test article	Bolted tyre wall, 16 long x 2 high, conveyor
	belt front, back against concrete barriers.
Installation length	10.1 m
Height of barrier	Nominal 420 mm (400mm to 440mm)
Material	Passenger car tyres, nom. 205 x 65R x 15"
Weight of barrier	378 Kg plus concrete barriers
Installation	Free standing on painted steel and
	concrete floor φ = 0.4
Test vehicle	Rimo EVO 6 Go Kart
Designation	#8 ID: 071312724
Test mass (incl. ATD)	225.5kg
Impact speed	25.2 km/h
Impact angle	90 degrees
Exit speed	
Exit angle	

Occupant Impact Velocity	Actual	*Preferred*	*Maximum*
Longitudinal (Vx)	**7.5**	*9*	*12*
Lateral (Vy)	**-0.1**	*+/-9*	*+/-12*
'Occupant impact' time	0.147 s		
Ridedown Acceleration	Actual	*Preferred*	*Maximum*
Longitudinal (Gx)	**-2.7**	*-15*	*-20*
Lateral (Gy)	**-1.0**	*+/-15*	*+/-20*
Permanent barrier deflection	x-direction	0.23m *(0.29m concrete)*	
Maximum Cof Gx (g)	-7.9g @ 83.6ms		
Maximum Cof Gy (g)	1.6g @ 71.4ms		
Maximum Cof Gz (g)	-6.9g @ 400.4ms		
Maximum roll angle	0.7deg @ 176.4ms		
Maximum pitch angle	-4.7deg @ 244.9ms		
Maximum yaw angle	-0.4deg @ 65.2ms		

Observations:
No damage to vehicle or tyre barrier. Dynamic penetration greater than residual deflection of 230mm. Concrete barrier displaced 290mm. Rear tyres of kart became airborne during rebound. Helmet visor opened and contacted steering wheel during impact.

Crashlab Test Number: B14014 **Summary of Results** **Test Date: 25 March, 2014**



Test article	Bolted tyre wall, 16 long x 2 high, conveyor
	belt front, against rigid concrete wall.
Installation length	10.1 m
Height of barrier	Nominal 420 mm (400mm to 440mm)
Material	Passenger car tyres, nom. 205 x 65R x 15"
Weight of barrier	378 Kg plus concrete wall
Installation	Free standing on painted steel and
	concrete floor φ = 0.4
Test vehicle	Rimo EVO 6 Go Kart
Designation	#8 ID: 071312724
Test mass (incl. ATD)	225.5kg
Impact speed	25.3 km/h
Impact angle	90 degrees
Exit speed	
Exit angle	

Occupant Impact Velocity	Actual	*Preferred*	*Maximum*
Longitudinal (Vx)	**8.2**	*9*	*12*
Lateral (Vy)	**-0.0**	*+/-9*	*+/-12*
'Occupant impact' time	0.147 s		
Ridedown Acceleration	Actual	*Preferred*	*Maximum*
Longitudinal (Gx)	**-2.7**	*-15*	*-20*
Lateral (Gy)	**-1.5**	*+/-15*	*+/-20*
Permanent barrier deflection	x-direction	-0.02m	
Maximum Cof Gx (g)	-8.9g @ 98.3ms		
Maximum Cof Gy (g)	2.5g @ 455.7ms		
Maximum Cof Gz (g)	-6.9g @ 445.1ms		
Maximum roll angle	-1.3deg @ 302.3ms		
Maximum pitch angle	-5.8deg @ 270.4ms		
Maximum yaw angle	-2.8deg @ 491.7ms		

Observations:
No damage to vehicle or barrier. Front face of barrier rebounded off wall by 20mm. Helmet visor opened and then detached after helmet made contact with steering wheel. Rear tyres of the kart became significantly airborne during rebound off the barrier.

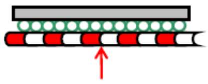
Crashlab Test Number: B14015 **Summary of Results** **Test Date: 25 March, 2014**

Test article	Bolted tyre wall (16 x 2), conveyor front,
	back to double height loose tyres & wall.
Installation length	10.1 m
Height of barrier	Nominal 420 mm (400mm to 440mm)
Material	Passenger car tyres, nom. 205 x 65R x 15"
Weight of barrier	378 Kg plus concrete wall
Installation	Free standing on painted steel and
	concrete floor φ = 0.4
Test vehicle	Rimo EVO 6 Go Kart
Designation	#8 ID: 071312724
Test mass (incl. ATD)	225.5kg
Impact speed	25.2 km/h
Impact angle	90 degrees
Exit speed	
Exit angle	

Occupant Impact Velocity	Actual	*Preferred*	*Maximum*
Longitudinal (Vx)	**7.0**	*9*	*12*
Lateral (Vy)	**-0.1**	*+/-9*	*+/-12*
'Occupant impact' time	0.168 s		
Ridedown Acceleration	Actual	*Preferred*	*Maximum*
Longitudinal (Gx)	**-3.0**	*-15*	*-20*
Lateral (Gy)	**0.6**	*+/-15*	*+/-20*
Permanent barrier deflection	x-direction	-0.10m	
Maximum Cof Gx (g)	-6.9g @ 29.9ms		
Maximum Cof Gy (g)	1.1g @ 47.1ms		
Maximum Cof Gz (g)	-2.6g @ 373.1ms		
Maximum roll angle	-0.7deg @ 261.8ms		
Maximum pitch angle	-2.2deg @ 247.4ms		
Maximum yaw angle	-2.4deg @ 543.0ms		

Observations:
No damage to vehicle or barrier. Front face of barrier rebounded off tyres and wall by 100mmon centreline and by 180mm and 220mm on the left and right ends respectively. The helmet visor opened and made light contact with steering wheel but remained attached to the helmet. Rear tyres of the kart became significantly airborne during rebound off the barrier.

Crashlab Test Number: B14016 **Summary of Results** **Test Date: 25 March, 2014**

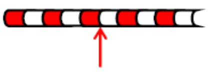
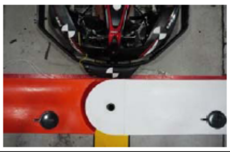
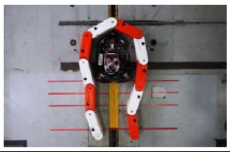
Test article	10 linked plastic barriers, 35kg water in each
	against double height loose tyres & wall.
Installation length	10.1 m
Height of barrier	Nominal 575mm
Material	Moulded plastic designed to hold water
Weight of barrier	550Kg (10 x 20kg barrier +10 x 35kg water)
Installation	Free standing on painted steel and
	concrete floor φ = 0.4
Test vehicle	Rimo EVO 6 Go Kart
Designation	#8 ID: 071312724
Test mass (incl. ATD)	225.5kg
Impact speed	25.3 km/h
Impact angle	90 degrees
Exit speed	
Exit angle	

Occupant Impact Velocity	Actual	*Preferred*	*Maximum*
Longitudinal (Vx)	**7.4**	*9*	*12*
Lateral (Vy)	**-0.0**	*+/-9*	*+/-12*
'Occupant impact' time	0.147 s		
Ridedown Acceleration	Actual	*Preferred*	*Maximum*
Longitudinal (Gx)	**-2.8**	*-15*	*-20*
Lateral (Gy)	**1.2**	*+/-15*	*+/-20*
Permanent barrier deflection	x-direction	-0.10m	
Maximum Cof Gx (g)	-12.4g @ 17.4ms		
Maximum Cof Gy (g)	-3.3g @ 60.8ms		
Maximum Cof Gz (g)	5.7g @ 14.4ms		
Maximum roll angle	0.8deg @ 197.8ms		
Maximum pitch angle	-2.1deg @ 224.7ms		
Maximum yaw angle	-0.2deg @ 25.6ms		

Observations:

No damage to vehicle or barrier. The plastic barrier rebounded off the loose tyres. The barrier rebounded 100mm along the centreline of the impact and 250mm and 225mm at the next connection points to the left and right respectively. The helmet visor opened and the top edge of the helmet opening contacted the steering wheel before the visor was dislodged. Rear tyres of kart became moderately airborne on rebound off barrier.

Crashlab Test Number: B14017 **Summary of Results** **Test Date: 25 March, 2014**

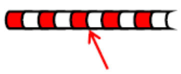
Test article	10 linked plastic barriers, 35kg water in each
	free standing on floor.
Installation length	10.1 m
Height of barrier	Nominal 575mm
Material	Moulded plastic designed to hold water
Weight of barrier	550Kg (10 x 20kg barrier +10 x 35kg water)
Installation	Free standing on painted steel and
	concrete floor φ = 0.4
Test vehicle	Rimo EVO 6 Go Kart
Designation	#8 ID: 071312724
Test mass (incl. ATD)	225.5kg
Impact speed	25.2 km/h
Impact angle	90 degrees
Exit speed	
Exit angle	

Occupant Impact Velocity	Actual	*Preferred*	*Maximum*
Longitudinal (Vx)	**3.4**	*9*	*12*
Lateral (Vy)	**0**	*+/-9*	*+/-12*
'Occupant impact' time	0.241s		
Ridedown Acceleration	Actual	*Preferred*	*Maximum*
Longitudinal (Gx)	**-0.6**	*-15*	*-20*
Lateral (Gy)	**0.6**	*+/-15*	*+/-20*
Permanent barrier deflection	x-direction	4.00m	
Maximum Cof Gx (g)	-11.4g @ 19.1ms		
Maximum Cof Gy (g)	2.7g @ 81.1ms		
Maximum Cof Gz (g)	-4.5g @ 28.6ms		
Maximum roll angle	0.3deg @ 180.1ms		
Maximum pitch angle	-0.7deg @ 159.9ms		
Maximum yaw angle	0.6deg @ 296.4ms		

Observations:

No damage to vehicle or barrier. Vehicle pocketed at point of impact and penetrated into barrier 4.00 meters with no rebound.

Crashlab Test Number: B14018 **Summary of Results** **Test Date: 25 March, 2014**





Test article	10 linked plastic barriers, 35kg water in each
	Free standing on floor.
Installation length	10.1 m
Height of barrier	Nominal 575mm
Material	Moulded plastic designed to hold water
Weight of barrier	550Kg (10 x 20kg barrier +10 x 35kg water)
Installation	Free standing on painted steel and
	concrete floor φ = 0.4
Test vehicle	Rimo EVO 6 Go Kart
Designation	#8 ID: 071312724
Test mass (incl. ATD)	225.5kg
Impact speed	50.1 km/h
Impact angle	25 degrees
Exit speed	
Exit angle	> approach

Occupant Impact Velocity	Actual	*Preferred*	*Maximum*
Longitudinal (Vx)	**4.5**	*9*	*12*
Lateral (Vy)	**3.7**	*+/-9*	*+/-12*
'Occupant impact' time	0.136 s		
Ridedown Acceleration	Actual	*Preferred*	*Maximum*
Longitudinal (Gx)	**-11.8**	*-15*	*-20*
Lateral (Gy)	**-11.2**	*+/-15*	*+/-20*
Permanent barrier deflection	x-direction		
Maximum Cof Gx (g)	-17.2g @ 105.4ms		
Maximum Cof Gy (g)	-13.9g @ 103.1ms		
Maximum Cof Gz (g)	-18.8g @ 380.6ms		
Maximum roll angle	3.0deg @ 270.8ms		
Maximum pitch angle	1.2deg @ 63.2ms		
Maximum yaw angle	-196.7deg @ 1,386.7ms		

Observations: No vehicle damage. Impact was at junction of 5th and 6th barrier in the 10 barrier assembly. Barrier 6, on the down stream side of the impact sustained a long fracture to the lower ridge line and leaked water. The kart rotated counter clockwise by more than 90 degrees as a result of the subsequent impacts with 5 barrier segments. The barrier assembly was displaced up to 6.3 meters longitudinally and 8m laterally. The Hybrid III right hand and lower forearm made heavy contact with two barriers during the impact.

Crashlab Test Number: B14019 **Summary of Results** **Test Date: 26 March, 2014**



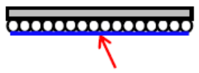


Test article	Bolted tyre wall, 16 long x 2 high, with
	conveyor belt front face.
Installation length	10.1 m
Height of barrier	Nominal 420 mm (400mm to 440mm)
Material	Passenger car tyres, nom. 205 x 65R x 15"
Weight of barrier	378 Kg (32 x 9kg/tyre + 90kg conveyor)
Installation	Free standing on painted steel and
	concrete floor φ = 0.4
Test vehicle	Rimo EVO 6 Go Kart
Designation	#8 ID: 071312724
Test mass (incl. ATD)	225.5kg
Impact speed	50.0 km/h
Impact angle	25 degrees
Exit speed	
Exit angle	None

Occupant Impact Velocity	Actual	*Preferred*	*Maximum*
Longitudinal (Vx)	**4.4**	*9*	*12*
Lateral (Vy)	**0.9**	*+/-9*	*+/-12*
'Occupant impact' time	0.225 s		
Ridedown Acceleration	Actual	*Preferred*	*Maximum*
Longitudinal (Gx)	**-1.8**	*-15*	*-20*
Lateral (Gy)	**3.8**	*+/-15*	*+/-20*
Permanent barrier deflection	x-direction		
Maximum Cof Gx (g)	-4.3g @ 16.5ms		
Maximum Cof Gy (g)	4.6g @ 369.0ms		
Maximum Cof Gz (g)	8.4g @ 529.2ms		
Maximum roll angle	2.0deg @ 376.2ms		
Maximum pitch angle	-2.2deg @ 232.7ms		
Maximum yaw angle	58.6deg @ 2,781.3ms		

Observations: The kart was not redirected by the barrier but continued in its forward direction lifting the convey belt and under-riding the barrier towards the down stream end. The kart's momentum drag the barrier forward before rotating clockwise. The longitudinal displacement of the barrier was up to 4.9m with a lateral displacement at the downstream end of almost 5m. The Hybrid III's right arm and helmeted head were impacted by the barrier which also bent the steering wheel backwards. The plastic fairing at the front of the kart was also cracked.

Crashlab Test Number: B14020 | **Summary of Results** | **Test Date: 26 March, 2014**



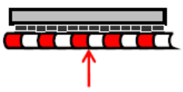


Test article	Bolted tyre wall, 16 long x 2 high, conveyor
	belt front, against rigid concrete wall.
Installation length	10.1 m
Height of barrier	Nominal 420 mm (400mm to 440mm)
Material	Passenger car tyres, nom. 205 x 65R x 15"
Weight of barrier	378 Kg plus concrete wall
Installation	Free standing on painted steel and
	concrete floor φ = 0.4
Test vehicle	Rimo EVO 6 Go Kart
Designation	#8 ID: 071312724
Test mass (incl. ATD)	225.5kg
Impact speed	50.0 km/h
Impact angle	25 degrees
Exit speed	
Exit angle	> approach

Occupant Impact Velocity	Actual	*Preferred*	*Maximum*
Longitudinal (Vx)	**8.0**	*9*	*12*
Lateral (Vy)	**2.0**	*+/-9*	*+/-12*
'Occupant impact' time	0.136 s		
Ridedown Acceleration	Actual	*Preferred*	*Maximum*
Longitudinal (Gx)	**-6.6**	*-15*	*-20*
Lateral (Gy)	--**2.8**	*+/-15*	*+/-20*
Permanent barrier deflection	x-direction	-0.53m	
Maximum Cof Gx (g)	-9.2g @ 157.0ms		
Maximum Cof Gy (g)	-5.8g @ 73.8ms		
Maximum Cof Gz (g)	9.8g @ 178.7ms		
Maximum roll angle	6.7deg @ 639.4ms		
Maximum pitch angle	-4.0deg @ 248.6ms		
Maximum yaw angle	127.0deg @1,455.5ms		

Observations: The kart commenced to under-run the barrier on impact without any redirection, until it pocketed and began rotating in a clockwise direction. The steering wheel was forced to turn hard right and was struck by the Hybrid III's helmeted head. The barrier rebounded off the concrete wall by up to 530mm. The back of the Hybrid III's right hand impacted the barrier during under-ride. There was no structural damage to the kart only some superficial scuffing on the front fairing.

Crashlab Test Number: B14021 | **Summary of Results** | **Test Date: 26 March, 2014**

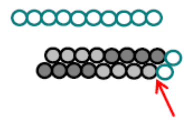




Test article	10 linked plastic barriers, 35kg water each,
	against row of standing loose tyres & wall.
Installation length	10.1 m
Height of barrier	Nominal 575mm
Material	Moulded plastic designed to hold water
Weight of barrier	550Kg (10 x 20kg barrier +10 x 35kg water)
Installation	Free standing on painted steel and
	concrete floor φ = 0.4
Test vehicle	Rimo EVO 6 Go Kart
Designation	#8 ID: 071312724
Test mass (incl. ATD)	225.5kg
Impact speed	50.0 km/h
Impact angle	25 degrees
Exit speed	Still to be calculated
Exit angle	< 15 degrees. (still to be checked)

Occupant Impact Velocity	Actual	*Preferred*	*Maximum*
Longitudinal (Vx)	**4.0**	*9*	*12*
Lateral (Vy)	**5.3**	*+/-9*	*+/-12*
'Occupant impact' time	0.136 s		
Ridedown Acceleration	Actual	*Preferred*	*Maximum*
Longitudinal (Gx)	**-6.9**	*-15*	*-20*
Lateral (Gy)	--**7.0**	*+/-15*	*+/-20*
Permanent barrier deflection	x-direction	0.03m	
Maximum Cof Gx (g)	-12.7g @ 44.2ms		
Maximum Cof Gy (g)	-13.9g @ 43.5ms		
Maximum Cof Gz (g)	7.7g @ 134.4ms		
Maximum roll angle	-1.9deg @ 476.9ms		
Maximum pitch angle	-1.1deg @ 210.9ms		
Maximum yaw angle	-54.8deg @1,000.0ms		

Observations: The kart was successfully redirected by the barrier with no pocketing and exit angle appearing to be within the allowable 15 degrees.. The two barriers that were impacted split at the lower ridge line with some loss of water. The filler cap was also forced off the first barrier impacted with some loss of water. The Hybrid III's right hand contacted the barrier during impact and the helmet head come close to contacting the top edge of the barriers. The maximum rebound of the barriers off the tyres and wall was no more than 30mm.





Test article	Tyre segments (4x2), double row overlapped
	With row of single loose tyres behind.
Installation length	5.6 m
Height of barrier	Nominal 420 mm (400mm to 440mm)
Material	Passenger car tyres, nom. 205 x 65R x 15"
Weight of barrier	324kg = 4 x 72kg (groups) +4 x 9kg (loose)
Installation	Free standing on painted steel and
	concrete floor φ = 0.4
Test vehicle	Rimo EVO 6 Go Kart
Designation	#8 ID: 071312724
Test mass (incl. ATD)	225.5kg
Impact speed	50.0 km/h
Impact angle	25 degrees
Exit speed	
Exit angle	

Occupant Impact Velocity	Actual	*Preferred*	*Maximum*
Longitudinal (Vx)	**5.9**	*9*	*12*
Lateral (Vy)	**-0.4**	*+/-9*	*+/-12*
'Occupant impact' time	0.136 s		
Ridedown Acceleration	Actual	*Preferred*	*Maximum*
Longitudinal (Gx)	**-2.3**	*-15*	*-20*
Lateral (Gy)	**3.0**	*+/-15*	*+/-20*
Permanent barrier deflection	x-direction		
Maximum Cof Gx (g)	-7.6g @ 42.1ms		
Maximum Cof Gy (g)	3.4g @89.2ms		
Maximum Cof Gz (g)	-4.8g @ 271.4ms		
Maximum roll angle	3.0deg @ 1,277ms		
Maximum pitch angle	-0.5deg @ 207.7ms		
Maximum yaw angle	157.4deg @2,099ms		

Observations: The kart was not redirected at all but rather immediately pocketed and commenced to rotate in a clockwise direction scattering the tyre bundles with it. The kart penetrated approximately 5.0m into the barrier arrangement and rotated 180 degrees from its original direction of travel.