NAFLIC

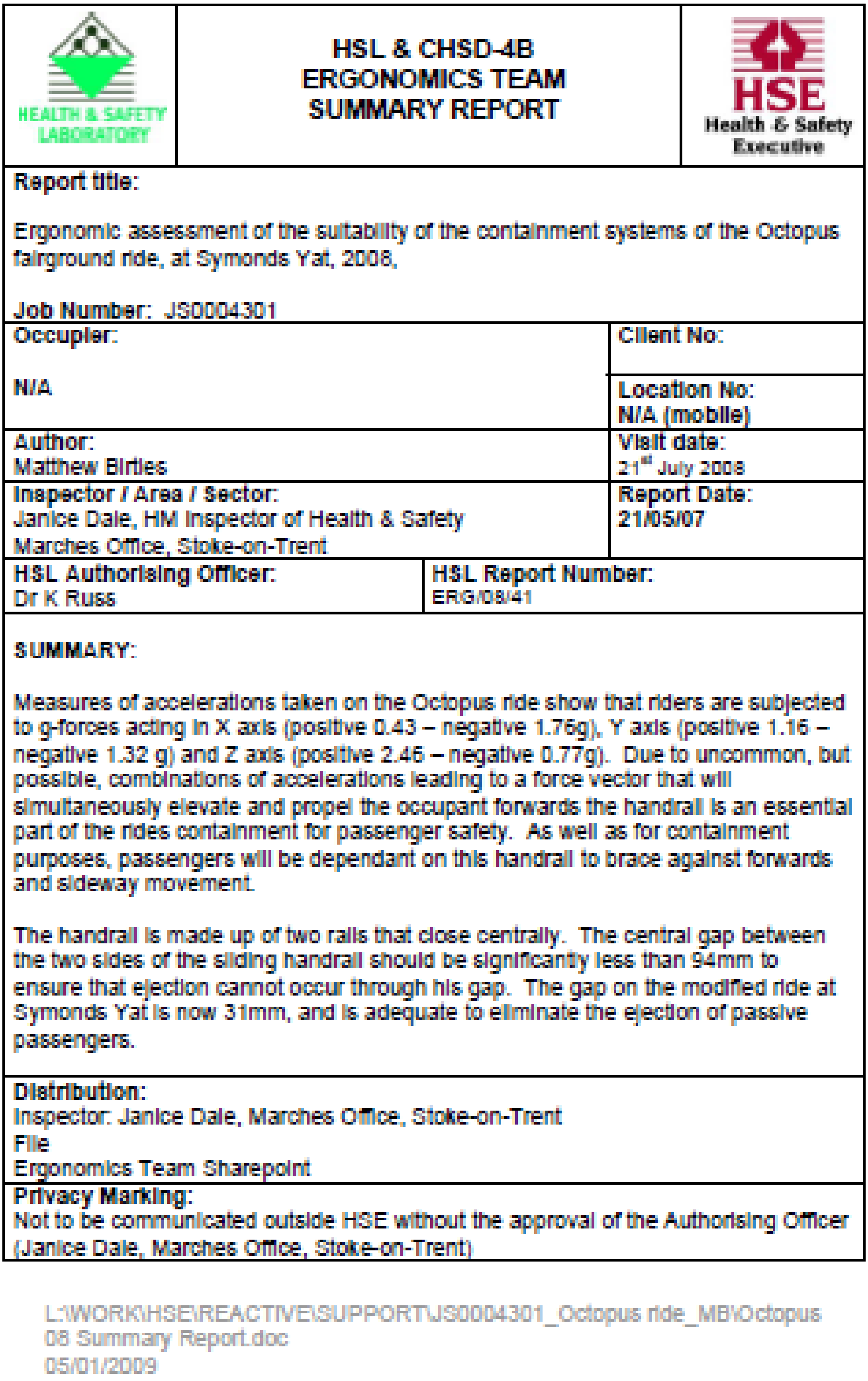
National Association For Leisure Industry Certification

Standards & Related Documents Committee

TECHNICAL BULLETIN – APRIL 2009

359. HSL Octopus Report ERG/08/41

The HSL has issued the following report to the industry. The report is an ergonomic assessment of the containment system of the Octopus fairground ride.



HSL & CHSD-4B ERGONOMICS TEAM SUMMARY REPORT

Report title:

Ergonomic assessment of the suitability of the containment systems of the Octopus fairground ride, at Symonds Yat, 2008,

Job Number: JS0004301

Occupier: N/A	**Client No:** **Location No:** **N/A (mobile)**
Author: Matthew Birtles	**Visit date:** 21st July 2008
Inspector / Area / Sector: Janice Dale, HM Inspector of Health & Safety Marches Office, Stoke-on-Trent	**Report Date:** **21/05/07**
HSL Authorising Officer: Dr K Russ	**HSL Report Number:** ERG/08/41

SUMMARY:

Measures of accelerations taken on the Octopus ride show that riders are subjected to g-forces acting in X axis (positive 0.43 – negative 1.76g), Y axis (positive 1.16 – negative 1.32 g) and Z axis (positive 2.46 – negative 0.77g). Due to uncommon, but possible, combinations of accelerations leading to a force vector that will simultaneously elevate and propel the occupant forwards the handrail is an essential part of the rides containment for passenger safety. As well as for containment purposes, passengers will be dependant on this handrail to brace against forwards and sideway movement.

The handrail is made up of two rails that close centrally. The central gap between the two sides of the sliding handrail should be significantly less than 94mm to ensure that ejection cannot occur through his gap. The gap on the modified ride at Symonds Yat is now 31mm, and is adequate to eliminate the ejection of passive passengers.

Distribution:
Inspector: Janice Dale, Marches Office, Stoke-on-Trent
File
Ergonomics Team Sharepoint

Privacy Marking:
Not to be communicated outside HSE without the approval of the Authorising Officer (Janice Dale, Marches Office, Stoke-on-Trent)

L:\WORK\HSE\REACTIVE\SUPPORT\JS0004301_Octopus ride_MB\Octopus 08 Summary Report.doc
05/01/2009

1.0 Introduction

At the request of HM Inspector Janice Dale I visited the Octopus ride at Symonds Yat West Leisure Park, Ross on Wye, Herefordshire, HR9 6BY on 21st July 2008 to perform an ergonomics assessment of the ride containment systems. This was following previous intervention from HM Inspector Dale when she had requested that the containment system be improved by closing a gap in the handrails where it was thought a small passenger could be ejected during ride operation.

1.1. Aims

The aim of the ergonomics assessment of the Octopus was to establish the effectiveness of the improved containment system (i.e. handrail and front car cover) as a means of preventing passengers being ejected from the ride (given the ride forces which will be experienced).

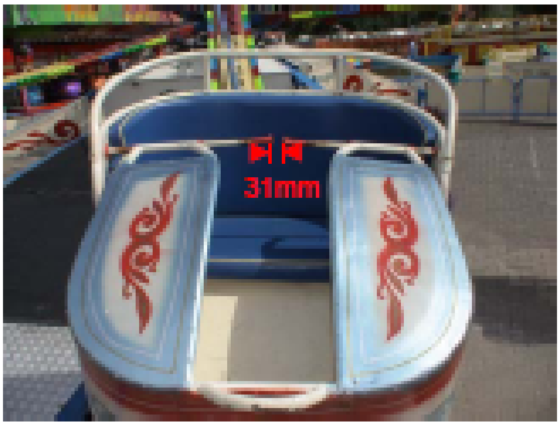
1.2 The Octopus Ride

The Octopus is a rotating ride with passenger cars that are pivoted on the end of a long elevating arms. During the rotation cycle the octopus tips, sending the passenger cars upward, so while experiencing two degrees of rotation the occupants are also elevated and lowered 3-4 times each rotation. A picture, taken from video of the ride is provided in Photograph 1.

Photograph 1 **Octopus ride mid cycle.**

After recent intervention from HM Inspector Janice Dale, the ride owner had altered part of the containment system to narrow a gap between the two sides of a horizontal, handrail that can be split and slid open to allow for passenger ingress/egress. The handrail is illustrated in Photograph 2. The ends of the rail had been extended so that when in the closed position, i.e. when the ride is occupied; there was gap of 31mm between the two ends whereas previously the gap had been of the magnitude of 170 – 180mm. In order to ingress into the ride, the entire ride front is tipped forwards and downwards (hinged at the area below the occupant's knee, as shown in Photograph 3). Each side of the containment handrail is then slid open to create a gap in the front where the riders can ingress/egress.

Photograph 2 Front view of the Octopus ride, showing the handrail in the closed position.



Photograph 3 Front view of the Octopus ride, showing the ride front tipped open and the handrail in the open position, to allow passengers to ingress/egress.

In order to ascertain whether the present, modified system of containment is adequate, measurement of the g force application of the ride were taken to understand the probable movements of the occupants experienced on the ride. Extra attention was given to whether the g forces experienced by the ride occupants would force them to travel forwards or upwards on the ride, and thus require the handrail for containment purposes.

2.0 Ride G Forces

2.1 Forces on passengers and passive forces on handrail

Forces on passengers

As the ride moves, passengers experience forces that can cause them to move in certain directions. This assessment of the forces on passengers and potential directions of passenger movement, assumes that passengers are not actively trying to move, i.e. they are sitting passively in the car.

If a passive passenger was experiencing ride forces acting forwards out of the seat or vertically upwards the passenger may elevate from their seated position towards the handrail. It is then essential that the handrail if adequately positioned to contain the passenger safely within the ride.

To assess the scope for passive passenger ejection, the ride forces were considered during the ride cycle. During this cycle the operator was asked to run the ride as fast as they felt confident to, without risking damage to the ride. This was reportedly slightly faster than they would run the ride when passengers were on, but not quite at the full speed of the ride. The ride forces are shown on the following graph, in each of the three directions of acceleration. These g-forces were measured for the purpose of this report using tri-axial pre-amplified accelerometer (Entran EGC83-A-25) fastened to the seat pan of the ride, at the occupant position. The ride discussed below represented a normal ride operation without passengers on the ride. I determined the duration of ride operation, while the speed of the ride was controlled entirely by the operator.

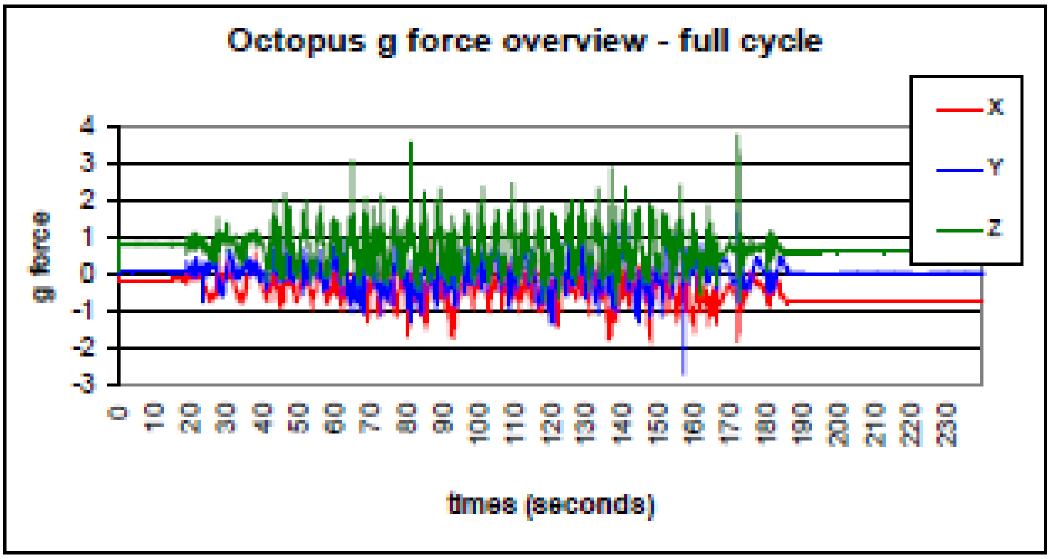


Figure 1. Measured Octopus ride accelerations during entire ride cycle

L:\WORK\HSE\REACTIVE\SUPPORT\JS0004301_Octopus ride_MB\Octopus 08 Summary Report.doc
05/01/2009

IMPORTANT NOTE:

All g-forces are described relative to the seat position (i.e. relative to the position of a seated person). For example a negative g-force in the x-axis would be a g-force that would push someone back against their seat back, regardless of the orientation of the ride relative to the ground at that point in time.

The convention for naming g-force directions are provided in Figure 2:

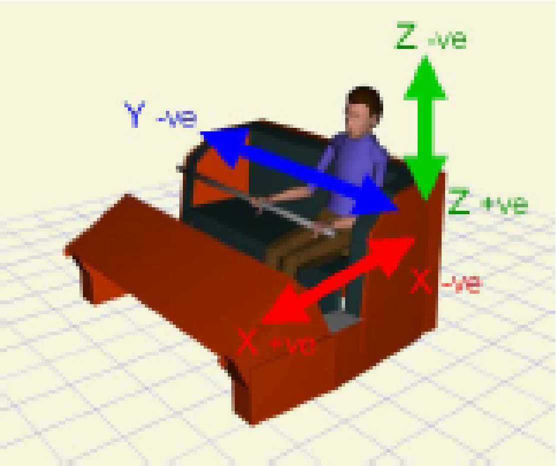


Figure2 **Illustrating the naming conventions of the effects of tri-axis g-forces on occupants of a fair ground ride.**

NOTE: arrows indicate resulting 'movement' of occupant.

- X-axis g-forces are fore/aft forces
    - Positive = pushing a person away from their seat back, sliding them forwards.
    - Negative = pushing a person into the seat back.

- Y-axis g-forces are side to side forces
    - Positive = pushing a person to their left hand side (e.g. the centrifugal force generated by the clockwise car rotation).
    - Negative = pushing a person to their right hand side (e.g. the centrifugal force generated by any (assumed) anti-clockwise car rotation).

- Z-axis g-forces are up/down forces
    - Positive = pushing a person downwards into their seat (e.g. the force felt due to gravity when seated stationary and on a surface which is horizontal relative to the ground).
    - Negative = pushing a person upwards out of their seat.

The plot for the entire ride (Figure 1) contains a significant amount of data which is difficult to see, so a representative plot taken of 30-second duration from the middle of the ride cycle is presented. This shall be used to discuss elements of g force noticeable during the ride activation. In total, 5 complete ride activations have been considered, 3 working normally without passengers and two with myself riding on the car that was being measured. There were few significant differences between the each activation, and so the following g force plot can be considered representative for all ride activations measured, unless otherwise mentioned.

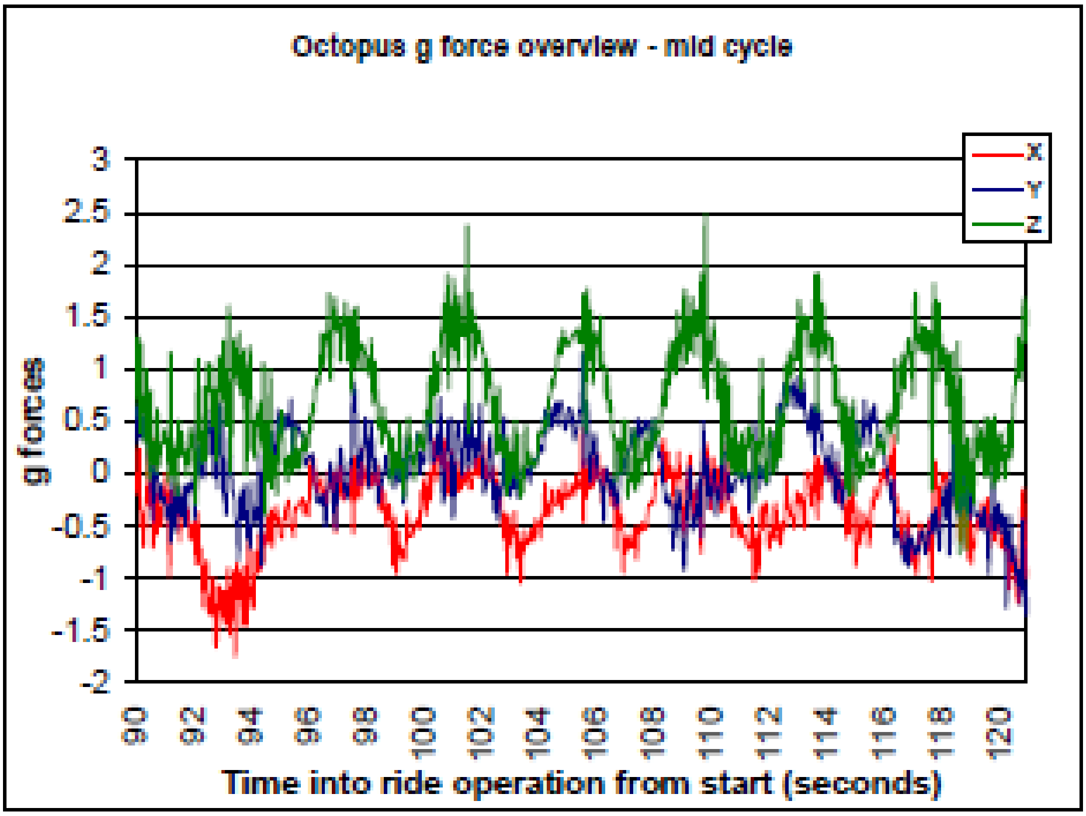


Figure 3. Measured Octopus ride accelerations during the middle 30 seconds of the cycle

In order to understand key aspects of this data, further guidance is provided on Figure 4, where key points of g force activity are highlighted and discussed.

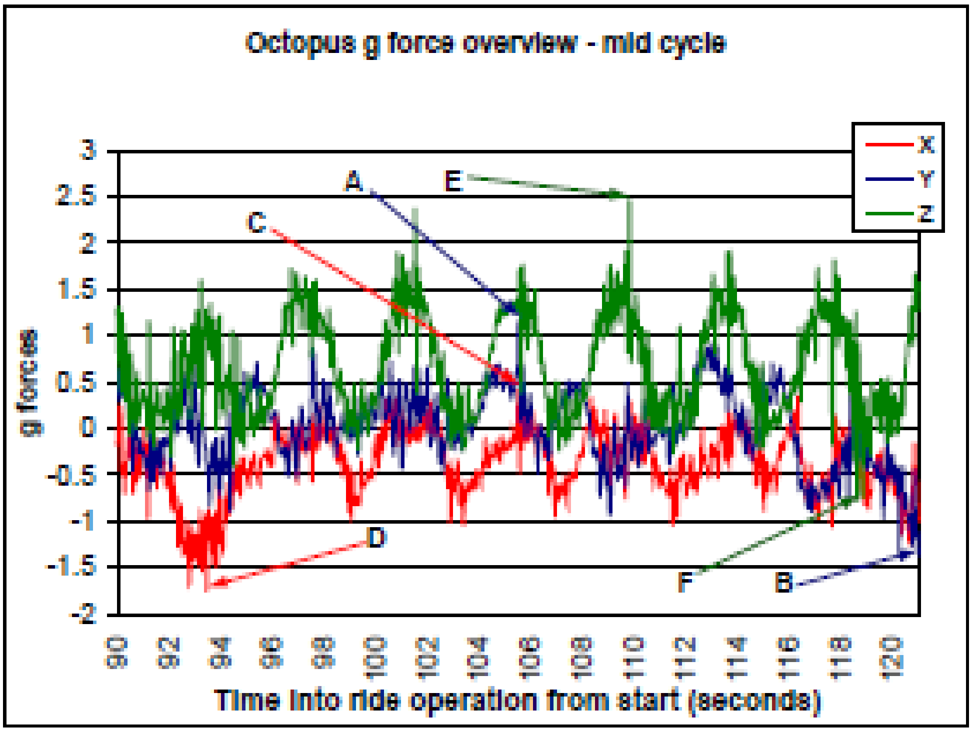


Figure 4. Key points of g-force activity during the middle 30 seconds of one representative ride cycle. The g force plots shown are a replica of Figure 3.

In Figure 4 the letters and arrows denote the following stages of a cars rotation during mid-ride movements (i.e. when the ride is running at normal operating speed):

A Shows a peak *positive* side-side (Y-axis) g-force (+1.16g) that moves passengers significantly to their left. This level represents a single, short peak in the +ve Y g-force which lasts approximately one twentieth of a second, at the end of a 4.5 second period of +ve Y g which was sustained at around 0.5g. The greatest magnitude of +ve Y g force measured over 5 rides was +1.7g. At such levels an occupant will be fall to their left hand side without actively bracing against these g forces.

B Shows a peak *negative* side-side (y-axis) g-force (-1.32g) that moves passengers significantly to the right. His occurs at the end of 2 second period of –ve Y g-force which increased from zero to this peak. The greatest magnitude of –ve Y g-force measured over 5 rides was –ve 2.7g, but this lasted only one twentieth of a second. During periods of lateral sideways acceleration the occupants are likely to actively brace using their feet and hands on the hand bar. They may shift to the side of the ride and use the sidewalls of the ride car to lean against during certain times of high acceleration, but such times would are not sustained for long periods.

C Shows a peak positive fore-aft (x-axis) g-force (0.43g)– which if experienced alone would push an occupant forwards on their seat. However, in this case, at the point C the vector combination of all g force is also pushing the occupant downwards into their seat pan (effectively making them heavier) which will mitigate the chance of an occupant movement significantly forwards. There may be a need to brace against such forces though, and the handrail offers the greatest affordance to do this.

D Shows a peak negative fore-aft (x-axis) g-force (-1.76g). At this point, and during the majority of the ride duration the occupant is being pushed backwards into their seat.

E Shows a peak positive vertical acceleration (z-axis) g-force (2.46g) where the occupant is being push downwards into the seat pan. This is common throughout much of the ride and the rider seldom feels completely 'weightless' in the vertical axis. However, for much of the ride operation the vertical g force is lower than +ve 1 (gravity) so the occupant will feel lighter, especially as the long arms of the ride lower. While ever the vertical g force is greater than zero a passive rider should remain in contact with the seat pan (unless they try to stand up).

F Shows a peak negative vertical acceleration (z-axis) g-force (-0.77g) – At this point the rider will have the sensation of being weightless, and could possible begin to lift off their seats. There are common occurrences where the vertical g force becomes less than zero (i.e. the occupant will feel weightless) and at each cycle, as the ride drops from one of the 2 elevations, the vertical g force tends to drop to between –0.2g to –0.3g. These negative z accelerations are of short duration and are seldom sustained longer than one fifth of a second (and are normally around one tenth of a second) before the g force fluctuates to greater than zero again. The cumulative distance of separation of the rider from the seat has been estimated at this time of peak negative g force occurring at around 118 seconds. This is illustrated in Figure 5. Overall the effect of even this highest peak g force is 0.55cm, which is considered negligible in terms of cumulative occupant movement.

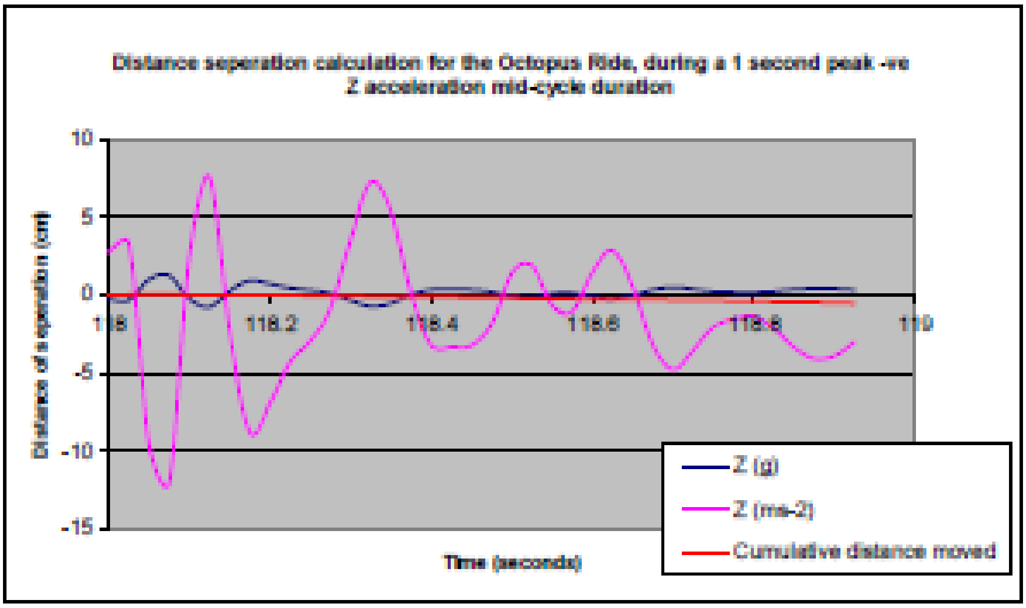


Figure 6. **Cumulative vertical distance of separation during 1 second of peak –ve Z accelerations, mid cycle of the Octopus Ride**

2.2 Synopsis of ride accelerations

Overall, the ride occupants will commonly be subjected to –ve Z and +ve X acceleration situations. These are obvious of interest, as exposure to such g force can elevate ride occupant upwards in relation to their seat or forwards. This then creates a need for appropriate containment. However:

- Negative Z axis (upwards) accelerations are not sustained.
- Negative Z axis (upwards) accelerations are not prolonged.
- Negative Z axis (upwards) accelerations are not of a high magnitude.
- Negative Z axis (upwards) accelerations are less frequent when the ride is occupied (but are more common when the ride is unoccupied and run at speeds that are reportedly slightly faster than normal).
- Negative Z axis (upwards) accelerations do not often occur with positive X axis accelerations, which would result in a force vector of elevating a person and sending them forwards. Such circumstances would require greater consideration and design of passenger containment systems. However, on the two occasions where they were recorded simultaneously (during fast ride activation when unoccupied) they were of low magnitude and would not significant cause passenger movement.
- Despite an absence of these in the recorded ride activations, due to the rotation of the passenger car, it is conceivable that negative Z and positive X axis accelerations will occasionally occur simultaneously.
- Positive X axis (forwards) accelerations do occur frequently, and are generally around the magnitude of 0.4g, peaking generally 4 – 5 times each ride up to 0.8 – 0.9 g. These latter forces especially will push the occupant forwards, highlighting the importance of the presence of the containment handrail.
- Analysis of areas of peak ride operation, where there are peaks of negative Z axis (upwards) accelerations show that these are not sustained for long enough to produce actual elevation of the occupant from their seat for a distance greater than 0.6cm.

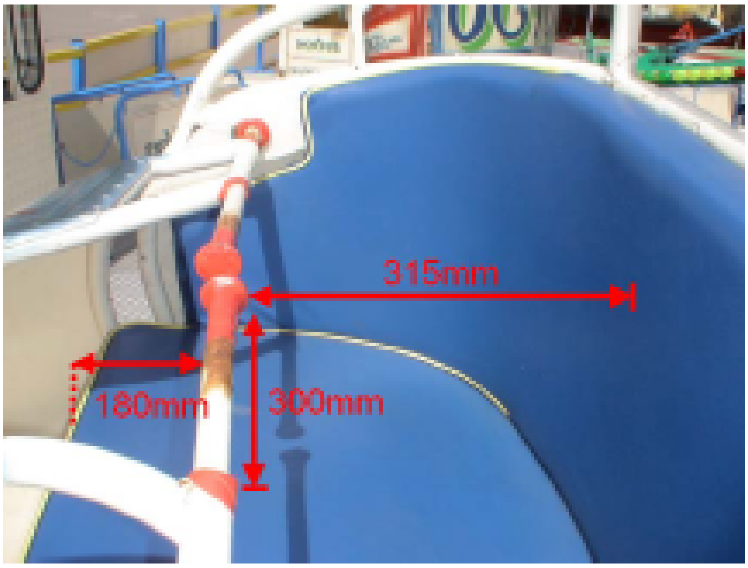
3. Efficacy of Containment System

While the effects of the vertical and horizontal peak g forces measured were considered to be only minor, they could product significant movement of a passenger, especially when experienced during ride rotation and sideways acceleration. Due to the ability of each passenger car to spin on it's own independent pivot, the movement of the Octopus cars are effectively random (or at least dependant on too many factors to be controlled, such as occupant size, weight distribution, movements, etc.). There may therefore be occasions where the combinations of g force produce a forward and upwards force vector. For this reason and for secure containment during the commonly experience sideways accelerations to which the occupants are subjected, an enclosed containment system is considered essential.

The relevant dimensions of the containment handrail and passenger car were measured and are provided in Photographs 4 – 6.

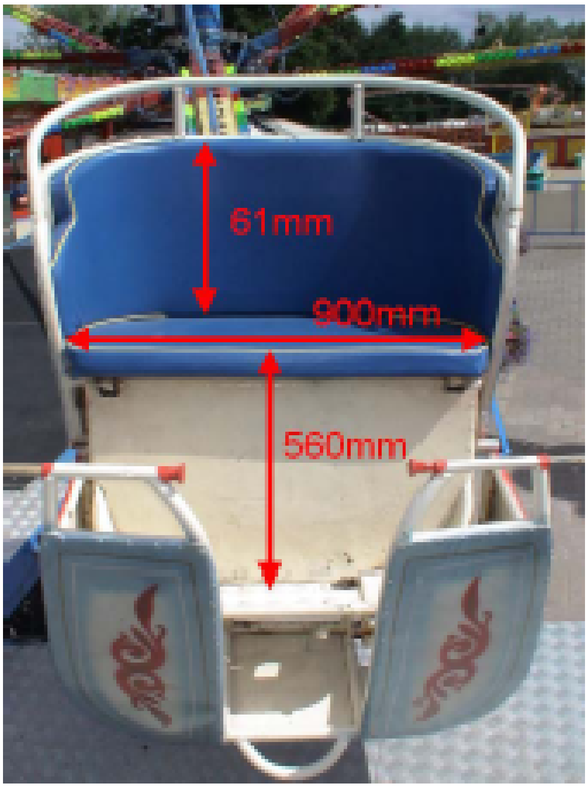
Photograph 4 Front view of the Octopus ride, showing the widths of the passenger car and width of the gaps in the containment.

Photograph 5 Side view of the Octopus ride, showing the depth of the passenger seat and position of the containment, hand bar.



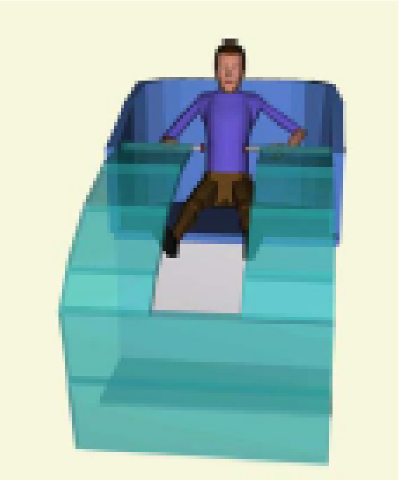
L:\WORK\HSE\REACTIVE\SUPPORT\JS0004301_Octopus ride_MB\Octopus 08 Summary Report.doc
05/01/2009

Photograph 8 Front view of the Octopus ride, showing the height of the passenger seat.



The width of the central opening between the two sides of the handrail has recently been reduced after intervention from the Inspector. Initially the centrally located gap between the two parts of the handrail was of the magnitude of 170 – 180mm (this is now measured at 31mm as shown in Photograph 4). This was based on measurements between the beginnings of the weld points on the altered handrail, where it has been extended. It is quite conceivable, given the magnitude of the lateral accelerations, that an occupant holding onto either the ends of the handrail or the rails at the side of the ride could rotate in their seat and instead of facing outwards face either side of the ride. In such circumstances, especially when coupled with a forward momentum the occupant may approach the handrail side on, at approximately waist height or if tall enough upper thigh height. To provide an indication of the approximate magnitude of the previous gap Figure 6 shows the previous gap width, according to the measures taken on 21st July, 2008 with a 50th percentile, 7 year old child in the ride. A visual comparison between the handrail gap and the child's waist width does indicate that ejection through the gap might have been possible.

Figure 8. **JACK Illustration of a 50th percentile 7 year old boy on the Octopus. A central gap between the two sides of the handrail, measuring 175mm is illustrated.**



The depth of the waist is one of the narrower parts of the body and when subjected to a compression force will narrow by approximately 19% in width (source, HSL testing, reported in HSL report ERG/06/26). To prevent an ejection under such conditions the central gap between the two sides of the handrail would need to be less than the depth of the abdomen, when in it's compressed state. The depth of the abdomen for 1st percentile adults and for 1st percentile 7 year old girl (who would be the thinnest children to every ride) are provided in Table 1:

1st percentile abdominal depth for: adults 7 year old girl	 164 mm 11.6 mm
Estimated, compressed 1st percentile abdominal depth for: adults 7 year old girl	 133 mm 94 mm

Table 1 **Abdominal depths for smallest (1st percentile) adults and children aged 7 years old before and after being subjected to compression.**

Given that the compressed abdominal depths for 1st percentile adults, and especially children are considerably smaller than the previous central gap between the two sides of the handrail it would have been possible for ejection to occur through this route. Closing the gap to 31mm has effectively eliminated this risk of ejection through the central gap in the handrail. Consideration should be given to the design of equivalent rides throughout the UK, and measures should be taken to eliminate or minimise the central gap in the handrail where these exist. Any such gaps should be significantly less than the 94mm to ensure that thinner children are not at risk of ejection in this manner with extra allowance for a safety margin.

Figure 76. **JACK Illustration of a 50th percentile male adult on the Octopus ride.**

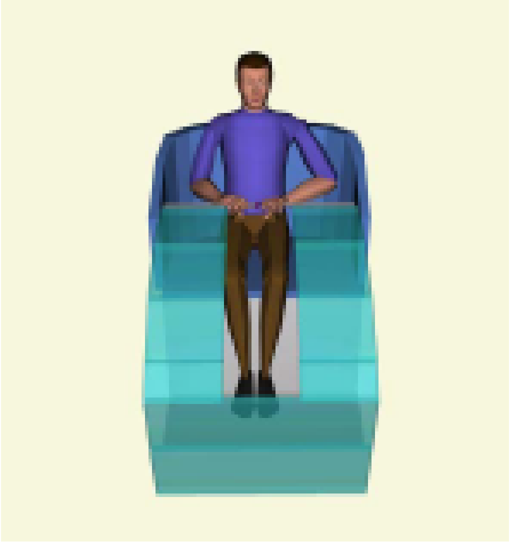
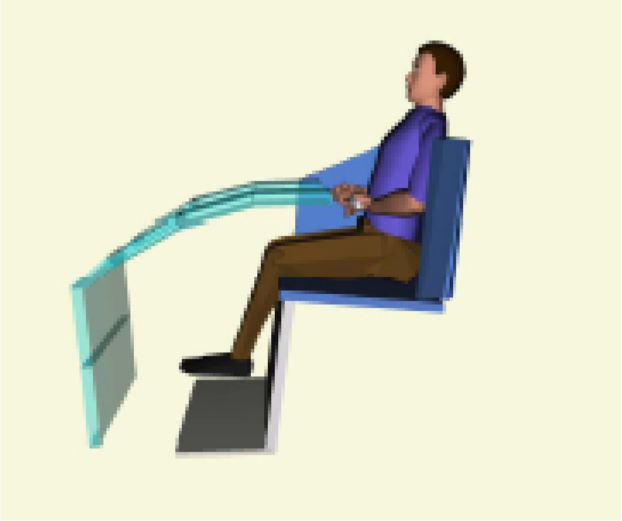


Figure 7 shows a model of a 50th percentile adult sitting with his back against the backrest. The model is based on the dimensions of the ride measured during the site visit on 21st July, 2008. Given that there were not instances recorded where the g forces were of the vector magnitude to cause serious elevation of the occupant from the seat, there is very little to suggest that occupant ejection poses a risk on this ride. The rider will experience g forces that push them forwards onto the hand bar, but given the gap between the closed bar is around 31mm there is no opportunity to exit the ride in this direction once the hand bars are securely closed.

Figure 8. **JACK Illustration of a 50th percentile male adult on the Octopus ride, side view.**



The side view of the ride does show though that even the adult occupant will not be able to plant their feet on the floor of the ride due to the height of the seat pan (seat bottom) in relation to the position of the floor. The result of this is that the occupant will not always be able to use their feet and legs to brace against the accelerations caused by the movement of the ride, and will therefore be more dependant on the use of the hand bar. This emphasises the need for a more closed hand bar to increase the surface area of the bar available to the occupant(s) and further supports the action previously taken to close the gap at the centre, between the two sides of the hand bar. The lack of available floor upon which to brace the lower limbs will have an equal if not greater impact on small occupants.

Figure 9. **JACK Illustration of a 50th percentile 7 year old child adult on the Octopus**

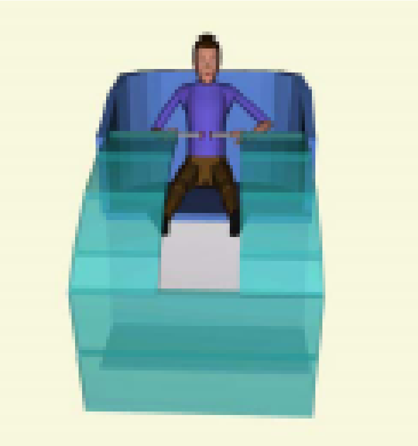
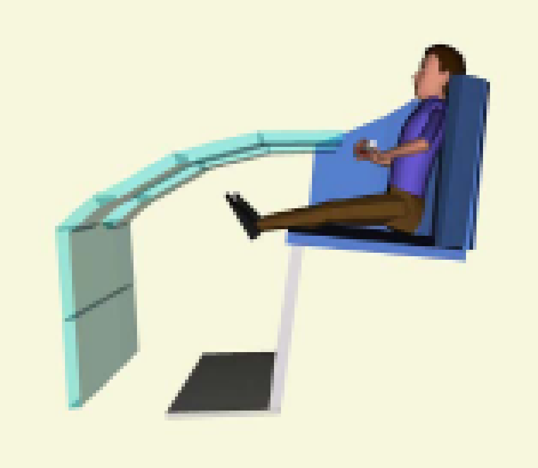


Figure 10. **JACK Illustration of a 50th percentile 7 year old child adult on the Octopus, side view**



In the case of the child, the ability to successfully reach and use the handrail is paramount, especially given that there is no scope to use the feet on the floor to actively brace against the forwards accelerations experienced on the ride. While there will be some scope for bracing with as the thighs against the seat pan, the handrail will remain essential for the occupant to stop themselves sliding forwards other than. Furthermore, given the significant lateral, sideways acceleration that will tend to result in the smaller occupant leaning sideways, during which they may experience forwards acceleration maximising the amount of handrail available to them is important.

As with the adult occupants though, the g forces are not of the magnitude to elevate and eject the passive passenger. The handrail will be used by the occupant to braces against the accelerations caused by exposure to the g force vectors, especially sideways movement and occasional forwards movement. Under the circumstance recorded during the observations it is my opinion that the particular containment, especially the modified handrail, on the Octopus Ride at Symonds Yat is adequate to effectively eliminate the risk of passive passenger ejection.

6. Conclusions

- The present design of the handrail is adequate, when considered for use under the conditions observed and recorded during the site visit 21st July 2008. This did involve running the ride at a maximum of ¾ speed and not full power.
- Owner of other Octopus rides should be encouraged to alter gaps in the handrails of other rides to reduce the gap to a distance as short as possible, and no more than