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HEALTH & SAFETY LABORATORY

Establishing criteria for safe g-force levels for passenger carrying amusement rides

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HEALTH AND SAFETY LABORATORY
An agency of the Health and Safety Executive

Summary

Objectives

1. To establish a database to record data from previous incidents, ride evaluation exercises and other research activities.

2. To increase the store of data as it is generated by literature review, research and incident investigations.

3. To assess the effects of g-forces and associated parameters on humans with a view to establishing levels of tolerance for members of the public.

4. To publish the information to ride designers, manufacturers, operators and user groups.

5. To produce proposals for inclusion in the draft European Standard for fairground ride design and fairgrounds guidance HS(G)175.

6. This report will describe the development of the database and the results of the various data interrogation procedures.

Main Findings

1. A database of incidents investigated by HSL Ergonomists was compiled and found to be a useable tool to review trends and important factors within the data.

2. The hypotheses that the majority of injuries were sustained when g-force levels were within documented limits of human tolerability and that the incidents were related to multiple ergonomics factors was accepted based on the interrogation of the database.

    2.1. Most incidents occurred on rides with measured accelerations within the documented allowable levels of g- forces.

    2.2. The g-forces were still important but were considered to be of secondary importance due to modifying factors related to the ergonomics of the passenger containment system as a whole.

    2.3. The majority of incidents involved ergonomics factors, principally:

        2.3.1. Passenger behaviour.

2.3.2. Passenger containment design.

2.3.3. The provision / ability of passengers to brace themselves.

3. Non application of basic ergonomics design principles was a major feature related to the incident data and the failings were common across a range of ride types. For instance:

3.1. A large proportion of database entries were found to have stature discrepancies in terms of their height restriction policy.

Main Recommendations

1. The database should be maintained, with the addition of new entries when new investigations are carried out.

2. It may be useful to carry out further reviews of the data:

2.1 Future comparison to the trends described in the database as it exists currently.

2.2 When further limit values for ride g-forces are published.

2.3 When other related guidance is published.

3. Further research is required in the area of fairground safety to help clarify several aspects raised in this report:

3.1. Passenger behaviour, in particular, with a focus on the behaviour of children on fairground rides.

3.2. The ability of passengers to brace and so stabilise their bodies as ride forces are applied. This needs to consider :

3.2.1. The range of passengers (adults and children).

3.2.2. Their strength capabilities.

3.2.3. And factors important to the coordination of a suitable bracing response.

3.3. The tolerability of ride g-forces by passengers. This should take account of:

3.3.1. The role of other ergonomics factors (such as the ability to brace effectively).

3.3.2. The variation and ranges of likely passengers (e.g. age and stature).

3.3.3. The forces associate with less serious symptoms and injuries that can be readily recovered from.

3.3.4. Definitions of tolerance for containment systems where g-forces are one of many factors to be considered together.

Contents

1. INTRODUCTION

Amusement rides have evolved at a dramatic rate over recent years into machines which immerse their passengers in a complex three dimensional force environment. Passengers can now experience more rapid changes in force direction and magnitude, with greater acceleration levels than ever before. However, the incidents investigated by the Health and Safety Laboratory (HSL) where ride g-force data has been collected have not all been on fast, modern rides. A discussion document (Jackson, 1998), produced for consideration by HSE Entertainment Section and the Fairgrounds Joint Advisory Committee (JAC), described a broad project outline for establishing criteria for safe levels of g-force on amusement rides based on data from incidents which HSL has helped to investigate. This project (jointly funded by FOD and TD) had the following aims and objectives:

i. To establish a database to record data from previous incidents, ride evaluation exercises and other research activities.

ii. To increase the store of data as it is generated by literature review, research and incident investigations.

iii. To assess the effects of g-forces and associated parameters on humans with a view to establishing levels of tolerance for members of the public.

iv. To publish the information to ride designers, manufacturers, operators and user groups.

v. To produce proposals for inclusion in the draft European Standard for fairground ride design and fairgrounds guidance HS(G)175.

The ergonomics section of HSL first started collecting amusement ride g-force data in 1995 as part of the amusement ride dynamics research project R49.003. The first measurements were made with a commercial system but there were practical problems which resulted in HSL developing their own hardware (Jackson, 1996). The logging hardware was named Fairlog by its developers, the Control and Instrumentation Section (CIS) in HSL. New ways of analysing the data produced by Fairlog were developed to help in assessing the effects of ride dynamics on passengers and the implications for the ergonomic design of passenger containment systems (Jackson & Ward, 1997) which introduced the concept of quadrant plots. Fairlog became a very effective tool in incident investigations which helped to promote further developments. Improved data analysis systems were also developed with the help of CIS software engineers which combined computer generated quadrant plots with time synchronised video recordings to produce video tapes for visual analysis of ride dynamics. This system was known as QPid (Jackson, 1997; Jackson & Monnington, 1999). Further developments have resulted in Fairlog II, which has more data channels and the use of digitised video for a computer based visual analysis system known as CDQPid. The Fairlog and QPid systems are still in demand, particularly in incident investigations, and their development continues.

The project was completed in two phases:

- Phase 1 involved the construction of the database and population of it with the available data.

- Phase 2 involved the development of search criteria and interrogation routines to analyse the data in the database.

Both these phases were iterative processes which called upon a multidisciplinary team with software engineering, ergonomics and data analysis skills.

This report will describe the development of the database and the results of the various data interrogation procedures.

Unfortunately, shifts in the timescales mean that the project has missed the production of the draft European Standard but the results may influence future revisions of the Standard and related guidance.

At various stages throughout the project members of the amusement industry were given opportunities to comment on the progress and emerging findings. The Fairgrounds Joint Advisory Committee Research Working Group were asked to comment on the final draft of this report. Their comments were both welcomed and carefully considered in the publication of this final report. It was particularly noted that they shared our concerns on the oversimplification of some of the issues relating to the g-force environment on amusement rides which were needed for direct comparison to published data. However, they were in broad agreement with the overall recommendations from this study.

2. IDENTIFICATION OF EXISTING DATA

2.1. Introduction

As described in section 1 the methods used to assist in the investigation and assessment of fairground ride ergonomics have changed rapidly since the first project was undertaken in 1995. One effect of such developments was a change in the range and type of information included in incident reports. There have also been incidents where it was not necessary to measure acceleration data to investigate accident causation e.g. human error and operating procedures problems.

2.2. Data sourcing and collection for inclusion in the database

In order to produce a specification for the project database it was necessary to identify which reports may contain relevant data and what data could be extracted in a reliable and consistent format.

Fairground incident reports from the HSL Ergonomics Section archive were gathered together. Relevant incident reports (reports containing acceleration data / reports of incidents where acceleration data was gathered) were then studied to identify what useful data was commonly available throughout.

Having made this initial investigation a spreadsheet was created which contained details of:

- Data that could be usefully included.
- The particular reports to be included in the database.
- The precise data each report contained.

This provided a list of data i.e. the data fields that had to be included in the database. For example, the type of ride, the body parts that were injured, maximum and minimum measured acceleration and containment system details etc.

The results of this initial information gathering process were discussed at project meetings involving the database designer. Initially, 14 separate incident reports were identified in this initial spreadsheet.

Two main issues were raised at the initial project meeting;

- Not all the relevant reports had been included in the spreadsheet. Further reports / incident investigations were identified by members of the project team as being relevant to the project. It was agreed that these should also be included in the database. It was also agreed that as incident investigations were completed during the course of the g-force database project, these should also be included in the database.

- Certain reports did not include all of the necessary data required in the database, however where additional data was needed, the original g-force and data files were revisited and analysed to gather the necessary data. This additional information gathering formed a major part of the overall data gathering process.

The initial database design was based on the spreadsheet, i.e. the database was designed so that fields were available to enter information on all the relevant and common data that had been identified. The spreadsheet in Appendix B provides a list of the data fields that were included in this first iteration of the database design (see Key to Data in Reports in Appendix B).

Once the initial version of the database had been designed and built, the relevant data from the incident reports were entered. This was checked several times for data entry errors. The structure and content of the database itself was also discussed at further meetings of the project team and with industry representatives on the JAC research committee and went through an iterative design process until a final version was agreed on. The final version included fields of relevant incident information, the fields of main interest in terms of interrogation of the data were:

- The measured accelerations:
  - Max. and min. g-forces
  - In 6 directions (and 3 axes):
    - Fore/aft (X), side to side (Y) and up/down (Z) axes
- Key incident factors:
  - Keyword - descriptors related to the main ergonomics concerns from each incident (e.g. bracing)
  - Injury type - classification of the injury (e.g. fracture)
  - Injured body zone(s) - (e.g. upper arms)
  - Injury mechanism - the main causes of the incident / injury (e.g. passenger ejection)
- Passenger containment system:
  - Height restriction discrepancies
  - Ride dimension mismatches

3. DATABASE QUERY METHOD

The purpose of the database was to collate and then sort the data set. It enabled the data to be arranged and searched in terms of defined criteria. Developing a clear approach to the database queries was very important as there was a potentially large number of possible methods that could be adopted. The review of what type of queries could be used was mainly driven by required outcomes and Access programming methods / constraints. An annex (p 45) attached to this report describes the development of the database.

The hypotheses for the database interrogation were:

1. The majority of injuries were sustained when g-force levels were within documented limits of human tolerability .

2. The incidents were related to multiple ergonomics factors.

Following research group discussions and initial pilot interrogation of the database the following broad approaches were considered to provide a balanced review of the incident data available:

1. Queries to define the database. Description of the ride forces and key incidents factors as a whole.

2. Queries based on measured ride accelerations. Comparison of the data with published ride acceleration criteria.

3. Queries based on key incident factors.

4. Queries based on passenger height restrictions and their associated discrepancies.

3.1. Database definition

A query routine was designed to collate and display all ride acceleration data, suitable for exporting into a spreadsheet for analysis.

Relevant key incident factors were selected and manually input into a spreadsheet from the database enter/view interface. Broad categories of information were recorded and summarised:

- Ride types

- Ride location

- Injury type and body zones affected

- Injury severity

- Injury mechanisms

- Age ranges of injured passengers

3.2. Ride acceleration query

3.2.1. Published ride acceleration criteria

A review of available literature uncovered only two applicable sources of information outlining fairground ride acceleration criteria. These were:

- RWTUV, Fairground Rides Attractions with Calculated Safety.

- AS 3533.1 (1997), Amusement Rides and Devices Part 1: Design and Construction. Appendix D: Basic Facts on the Effects of Acceleration on the Human Body.

These were the basis of this stage of the database query. Table 1 outlines force levels suggested in the two sources which were applied to interrogate the database, while table 2 shows the values used to search for entries with higher ride forces.

Table 1. Ride acceleration (g.) criteria as extracted from the TUV and AS 3533.1 sources.

	X axis - fore/aft		Y axis - sideways		Z axis - up/down	
	Max.	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**
TUV lower levels	no data provided		2	-2	4	-1.5
TUV upper levels			3	-3	6	-2 (-1.7*)
AS 3533.1	2 - 3	no data	no data provided		3 - 5.5	-2.5

*value rounded up

The TUV values were used for examination of the Y and Z axial data. The data described in AS 3533.1 was similar for the Z axis and so therefore, felt to add little value to the evaluation. The fore/aft force were those described in AS 3533.1, specifically, a maximum force of 2 to 3 g, although no data was provided the same values (-2 to -3) were used for the minimum values (at least as a means to search the database). In addition, to allow better understanding of the ride accelerations a 1g (-1g) category was also added.

Table 2. The ride acceleration (g.) criteria used to interrogate the database.

	X axis - fore/aft		Y axis - sideways		Z axis - up/down	
	Max.	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**
Lower level criteria	2	-2	2	-2	4	-1.5
Upper level criteria	3	-3	3	-3	6	-2

The TUV values claimed to be specific to ride forces for roller coasters and were aimed to prevent injuries to the neck vertebrae. AS 3533.1 used data collected by the NASA space exploration program, this was published in the Bioastronautics Handbook (NASA, 1973). The strengths and weaknesses of these published sources are discussed in section 5 of this report.

3.2.2. Query method

The searches aimed to describe:

- The number of entries with ride accelerations outside the criteria described in table 2 and a summary of the key incident factors associated with the entries.
- The number of entries inside the ride acceleration criteria described in table 2 (see table 4) and a summary of the key incident factors associated with the entries.

Table 3. The database ride acceleration (g.) interrogation values based on those described in 3.2.1.

X axis	Y axis	Z axis
>1	>2	>4
>-1	>-2	>6
>2	>3	>-1.5
>-2	>-3	>-2
>3	>2 and >-2	>4 and >-1.5
>-3	>3 and >-3	>6 and >-2
>1 and >-1		
>2 and >-2		
>3 and >-3		

Table 4. The database ride acceleration (g.) interrogation values based on those described in 3.2.1.

X axis	Y axis	Z axis
1 to -1	2 to -2	4 to -1.5
2 to -2	3 to -3	6 to -2
3 to -3		3 to -1
		2 to -0.5

The interrogation values (table 3 and 4) were used to examine and group rides in terms of violation and agreement with these values, for:

- Single axis query, 1 or 2 directions (X, Y or Z).
- Double axis query, 3 or 4 directions (X and Y, Y and Z or X and Z).
- Triple axis, multi-directional queries (X, Y and Z; X and Y, Y and Z or X and Z).

3.3. Key incident factors query

For this query route a reverse approach to that described in 3.2 was adopted. A query form was used, as described in annex biii of this report, from which key incident factors could be selected. This provided an output displaying the database entries with the factors and their associated ride accelerations. The query outputs were exported into a spreadsheet for statistical analysis of the accelerations. In some instances further data sorting took place in the spreadsheet to augment the analysis process.

Table 5 shows a listing of the key incident factors used to search the database. These factors were used on their own and then in combination.

Table 5. Listings of key incident factors used to search the database.

Keyword Descriptors	Body zone injured	Injury Mechanism	Injury Type
Bracing	Head / neck	Passenger ejection	*Less serious:*
Containment	Trunk	Passenger behaviour	Cuts, bruises, abrasion, graze, pain, discomfort, muscle strain, nausea
Operating procedures	Upper limbs	Impacts	
Passenger selection	Other	Forces	
			Serious:
			Fatal, fractures, spinal injury, whiplash, crush, concussion

The following combination queries were made based on the key incident factors listed in table 5:

w Fatalities with	containment
"	passenger behaviour
"	forces (keyword)
"	passenger ejection.

w Passenger behaviour with passenger ejection.

w Injury type (serious or less serious) with	head/neck injury
"	forces (keyword)
"	impact
"	passenger selection
"	containment.

The combination factors were devised based on expertise and experience acquired during the various incident investigations. These were considered to relate to potentially interesting interactions concerning fairground ride safety. More complex key incident factor queries using 3 or more factors were possible using the database query form. However, these were found to be less effective in terms of sorting the data into groupings for discussion, and did not provide much additional information.

3.4. Stature discrepancy query

A database form was devised to output all entries which described a discrepancy between an operator's (or manufacturer's) ride restriction policy and those recommended in the HSL reports based on ergonomics data concerning human body size data and their associated ride critical dimensions. The output from the database was exported into a spreadsheet for analysis.

The analysis focused on:

w Number of entries

w The critical ride dimensions

w The height restrictions and associated age based on stature

w The recommended height restriction and associated age based on stature

w The ride's measured accelerations

4. DATABASE QUERY RESULTS

4.1. Database definition

The completed database contained 26 entries at the point when data interrogation began. At this point the entry of new incidents into the data set was suspended to ensure consistency across the query stage.

4.1.1. Ride types and location

The database consisted of rides located at theme parks, fixed attractions and temporary attractions. Most rides concerned were located at theme parks (42 % of entries) or temporary attractions (50 % of entries).

There was a considerable variation of ride types described in the database (a breakdown of the ride types is shown in appendix A). Many rides (38 % of entries) were single examples of their ride type, the exceptions being 10 coasters (38 % of entries), 3 twists (12 % of entries) and 3 tagadas (12 % of entries).

4.1.2. Ride forces

Table 6. The measured and summary ride forces for each axis as described in the database. Note for 2 rides the Y axis data was missing, two rides were also included in the database without measured ride forces. (* † violated acceleration criteria see 3.2.1 and 4.2.2).

	X axis - fore/aft		**Y axis - sideways**		**Z axis - up/down**	
	Min.	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
	-0.69	1	-1.48	0.24	0.77	1.13
	-0.02	0.34	-0.01	0.16	0.57	2.34
	0	0	-1.12	1.11	-0.14	2.17
	-1.28	1.16	-1.36	0.69	-0.21	1.99
	-0.3	1.9	-0.7	0.8	-0.3	2.3
	-1.22	0.63	-3.13*†	-1.22	0.31	3.97
	-1.93	2.54*	-1.99	1.86	-1.7*	1.5
	-2.31*	2.39*	no data	no data	-2.43*†	6.39*†
	-1.67	1.97	-1.52	1.12	-1.42	5.63*
	-1.42	0.65	-0.6	0.61	0.46	2.44
	-2.6*	4.24*†	-2.63*	1.61	0.49	1.76
	-1.21	1.35	-2.77*	2.16*	-1.94*	3.17
	-0.3	1.5	-0.8	0.6	-0.4	2.5
	-0.63	2.29*	-1.41	1.47	0.79	1.17
	-0.56	0.97	-1.89	2.43*	-1.01	3.48
	-0.41	0.71	-0.4	0.39	0.65	1.43
	-0.87	1.98	-1.04	0.99	-3.79*†	1.05
	-0.1	1.6	-0.7	0.7	-0.2	2.2
	-1.52	1.88	-0.29	0.23	-0.54	3.17
	-1.6	2.8*	-1.8	1.8	-0.9	6.4*†
	-0.91	1.16	-0.98	0.53	-0.57	3.64
	-1.59	1.92	-2.78*	3.88*†	-1.42	6.14*†
	-0.97	2.39*	no data	no data	-3.29*†	5.78*
	-3.62*†	3.98*†	-6.24*†	1.26	0.13	1.18
Mean	-1.16	1.72	-1.62	1.06	-0.67	3.04
S.D	0.88	1.04	1.34	1.01	1.26	1.78
Range	3.62	4.24	6.23	5.1	4.58	5.35
Min.	-3.62	0	-6.24	-1.22	-3.79	1.05
Max.	0	4.24	-0.01	3.88	0.79	6.4

Table 6 shows the raw data and summary data from the measured ride forces in each direction from the database (see also figure 1). Figure 2 illustrates the peak ranges of the measured forces.

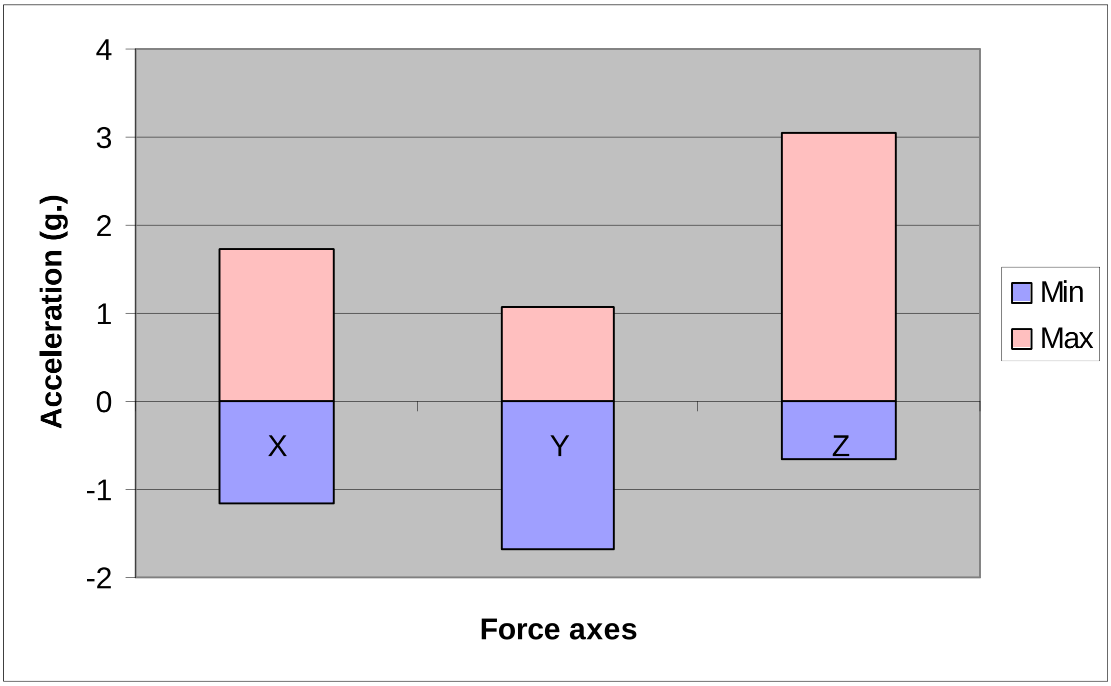


Figure 1. Mean maximum and minimum measured forces from the entries in the database.

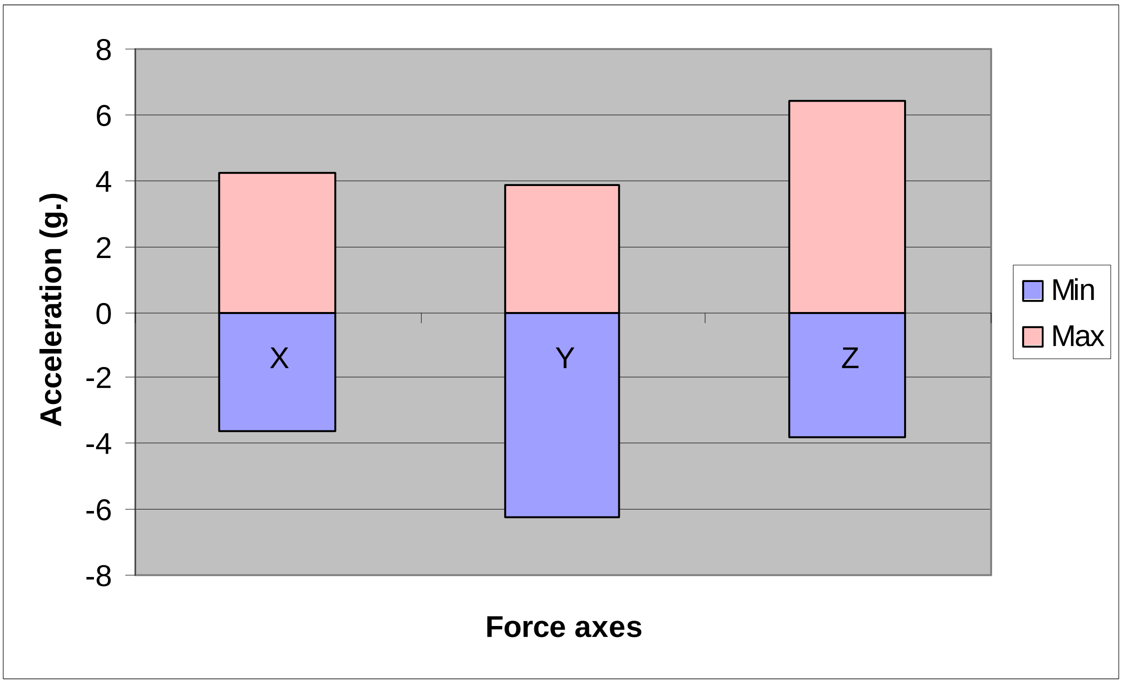


Figure 2. Peak measured forces from the database entries.

4.1.3. *Injury data*

It should be noted that the database only recorded the minimum and maximum ages of passengers injured on each ride and not the ages of all passengers injured on each ride. Passengers as young as 4 up to 43 years of age had sustained injuries described in the database.

The body zones injured during the incidents from the database are shown in figure 3. It was possible for each incident entry in the database to have more than 1 body zone specified, therefore, the data is displayed as a percentage of the total number of body zones selected in the database. Most injuries affected the head and neck region (50 % of total body areas (n=34) described in the database).

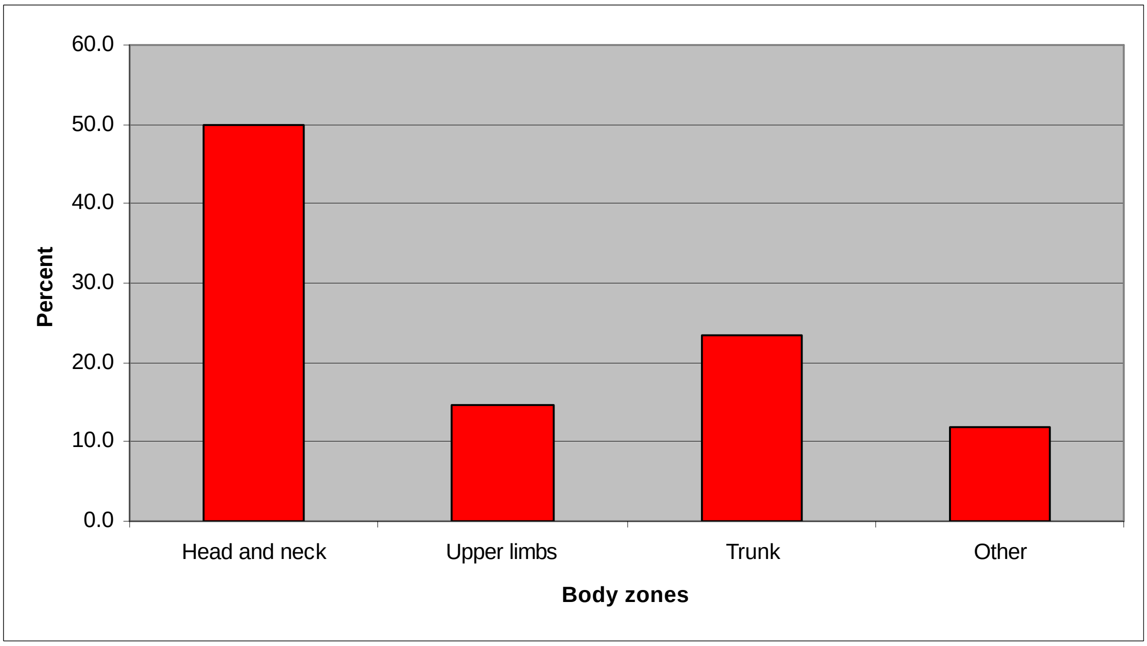


Figure 3. Body zones injured as a percentage of the total sample from the database.

The types of injury recorded are described in figures 4 and 5. It was possible for more than one injury type per database entry to be recorded. The types of injuries varied considerably (figure 4), 25 % of the total number of injuries (n=40) described involved bruising of some degree, 7 cases of fractured bones (18%) were recorded and 4 cases of whiplash (10%). Three (8% of total injury types) fatalities were recorded in the database. Other less frequent types of injuries were recorded and grouped but accounted for 20% of the total injuries, these included, abrasion, fainting, nausea, and pain / discomfort. There was an even distribution between injuries considered to be of a serious (e.g. fatality, fracture, concussion, spinal injuries, etc.) and less serious nature (e.g. bruising, pain, abrasion, nausea, etc.), illustrated in figure 5.

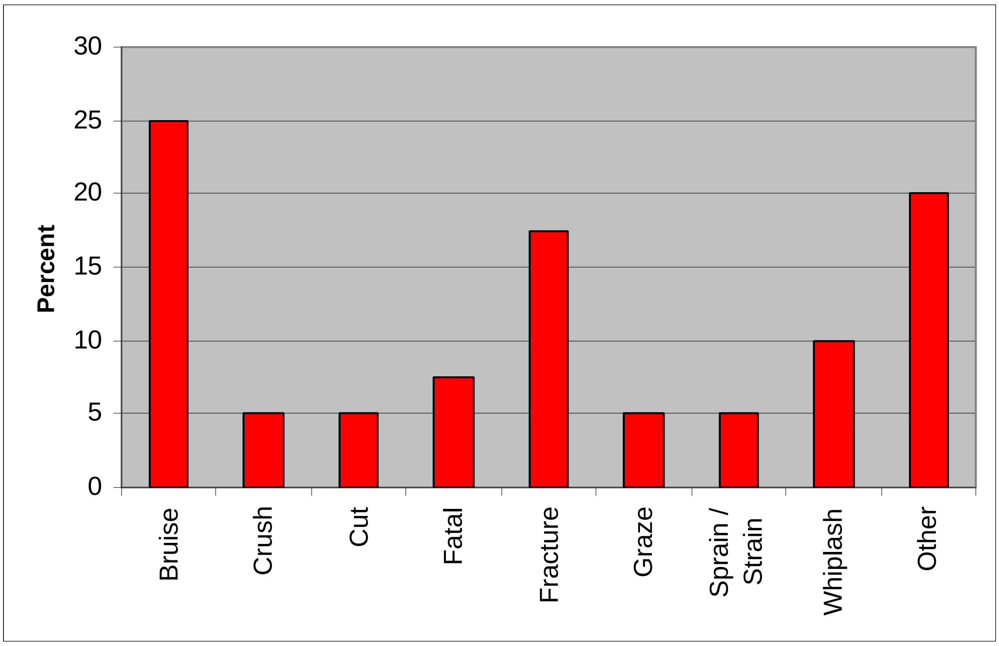


Figure 4. Types of injury as a percentage from the total injuries (n=40) described in the database.

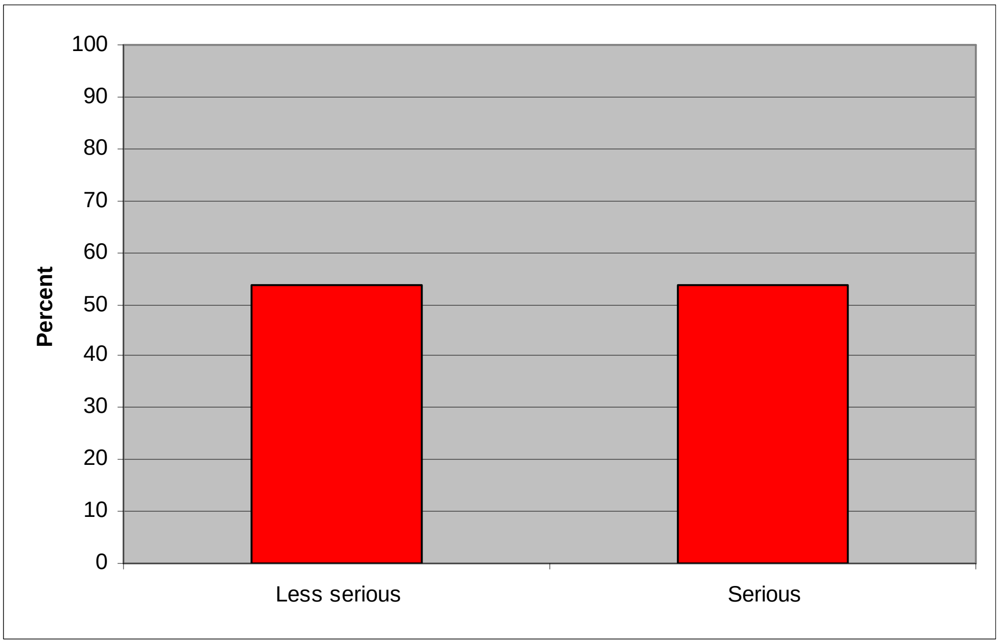


Figure 5. Combined injury types classified as less serious and serious injury types (percentage of total data entries n=26). No injury data was collected for 2 entries.

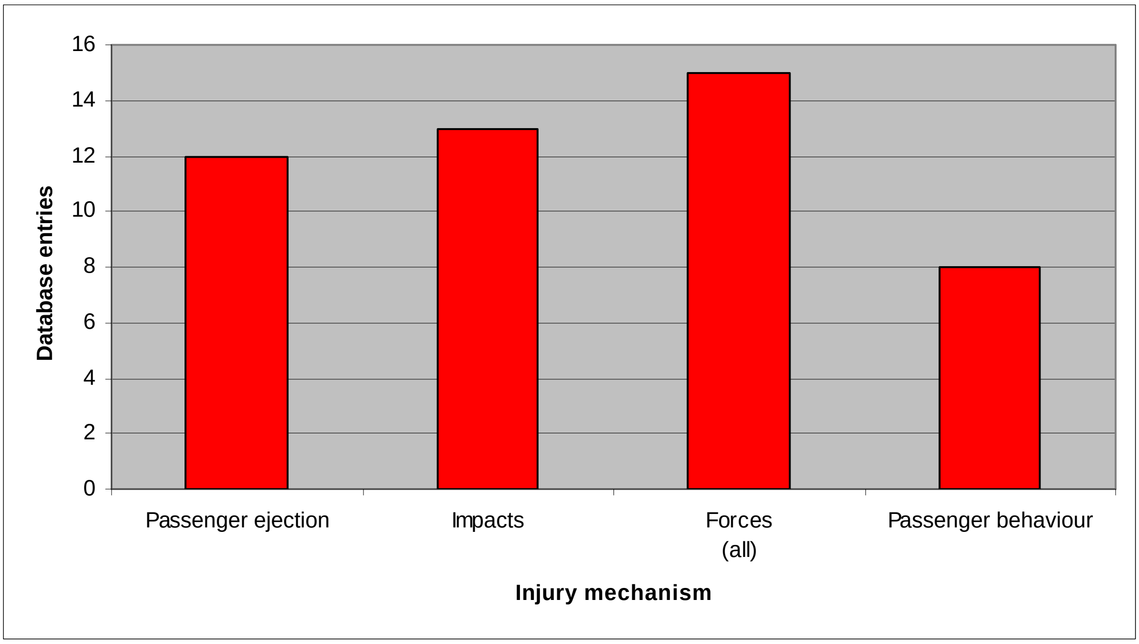


Figure 6. Combined injury mechanism frequencies described in the database.
Note, more than one injury mechanism is possible for each database entry. Forces (all) denotes entries with force related injury mechanisms and from keyword forces.

As with the other injury data it was possible to enter more than one injury mechanism for each incident record. The mechanisms with a role in the cause of the injuries (see figure 6) were combined into: passenger ejection (25% of the total number of injury mechanisms (n=48) described); impacts (27% made up of impacts with ride structures, containment components and other impacts); forces (31% made up of excessive forces, excessive onset of force, sustained forces, poor posture with force and other secondary force effects); and passenger behaviour (17%).

4.2. Ride acceleration query

4.2.1. Single axis, 1 or 2 directions

Outside values from table 3, the database ride acceleration interrogation values

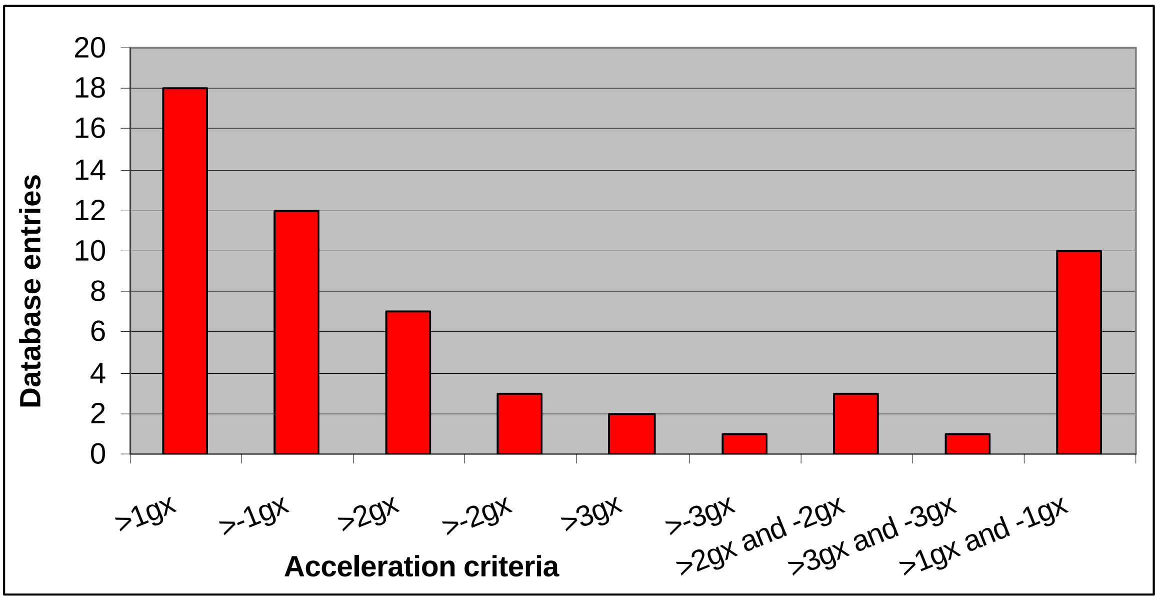


Figure 7. Database entries outside the values described in table 3 for the X axis.

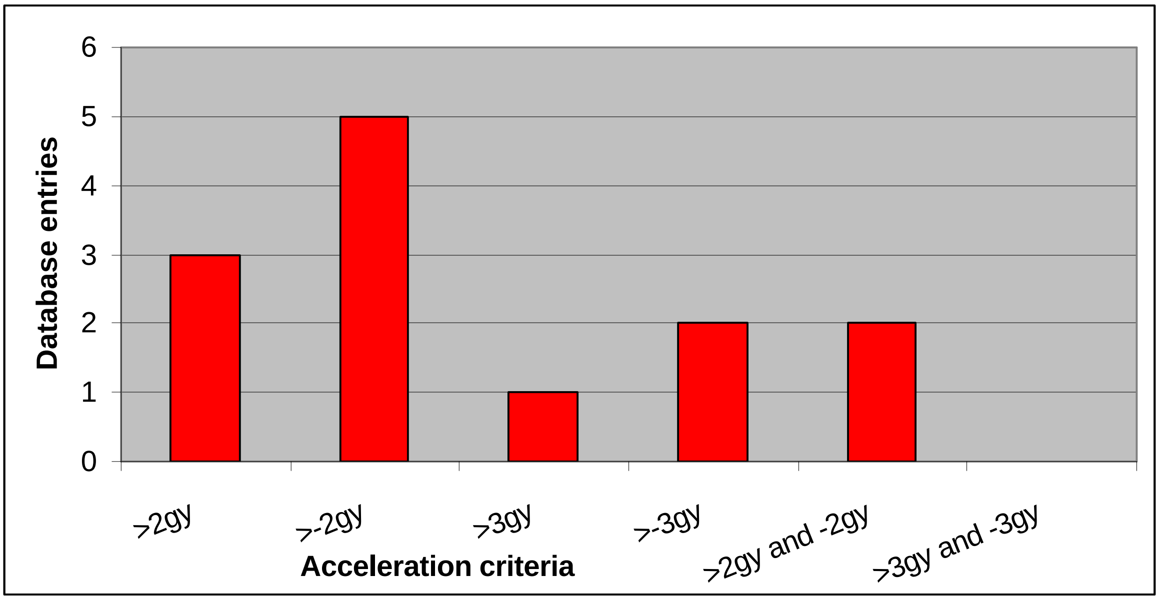


Figure 8. Database entries outside the values described in table 3 for the Y axis.

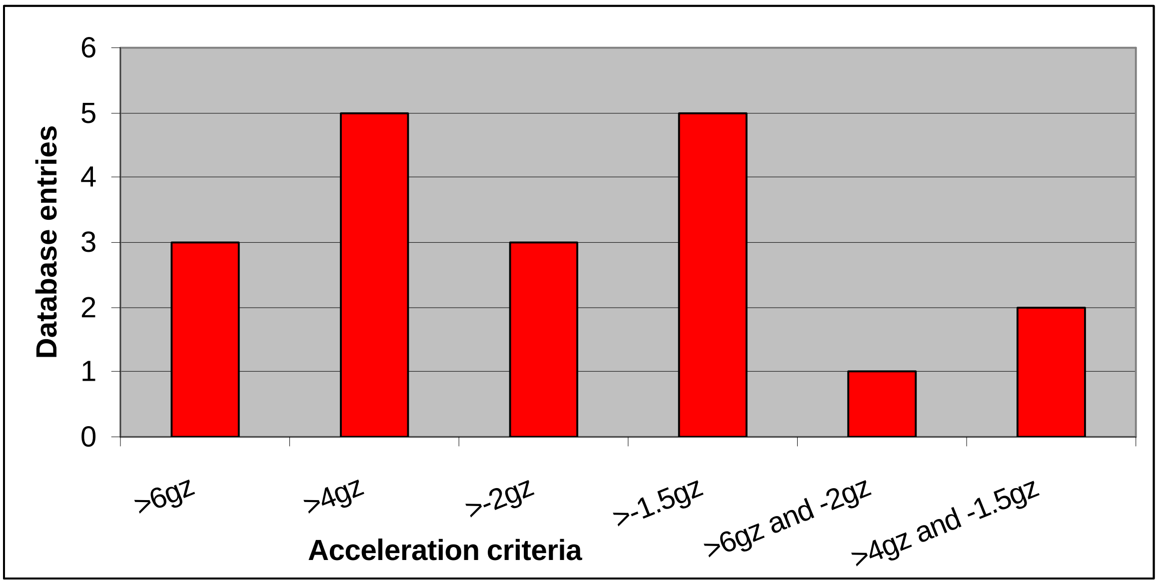


Figure 9. Database entries outside the values described in table 3 for the Z axis.

Accelerations outside the values from table 3 (including those outside the acceleration criteria described in table 2) are shown in figure 7 to 9. Violations of the upper and lower acceleration criteria were relatively few, between 3 and 7 entries for single direction accelerations. Violations in both directions for each axis were limited to between 0 and 3 entries.

Inside values from table 4

Accelerations inside the upper and lower acceleration criteria are described in figure 10. It can be seen that the majority of entries were within those levels. Several entries (3gz to -1gz) were found to be well within the criteria.

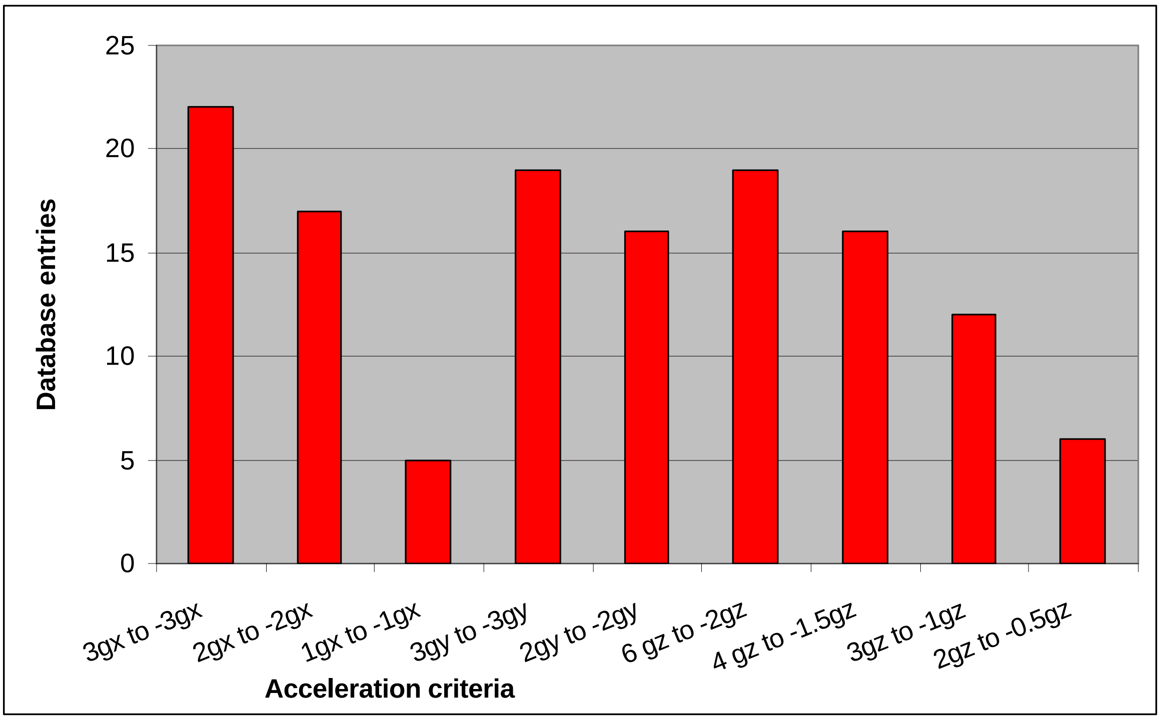


Figure 10. Database entries inside the values described in table 4 for the X, Y and Z axes.

4.2.2. Three axis, multiple directions

Outside criteria from table 2, the ride acceleration criteria used to interrogate the database

Examination of all acceleration directions found that 13 entries violated the lower level criteria described in table 2. Namely, accelerations greater than 2 g (X and Y axes), -1.5 and 4 g (Z axis). The precise violations are highlighted (*) in table 6 summarising the whole database. It can be seen that:

- 6 entries violated the criteria in 1 direction
- 1 entry violated the criteria in 2 directions
- 5 entries violated the criteria in 3 directions
- 1 entry violated the criteria in 4 directions

Eight entries violated the upper level criteria described in Table 2. This was set as accelerations greater than 3 g (X and Y axes), -2 and 6 g (Z axis). The violations are highlighted (†) in table 6. The violations were as follows:

- 5 entries violated the criteria in 1 direction

- 2 entries violated the criteria in 2 directions

- 1 entry violated the criteria in 3 directions

Figure 11 shows the key incident factors related to the entries which were found to violate the upper level criteria. Head and neck injuries, force or impact were involved with most of the entries (greater than 60%). Half of the entries involved serious injury.

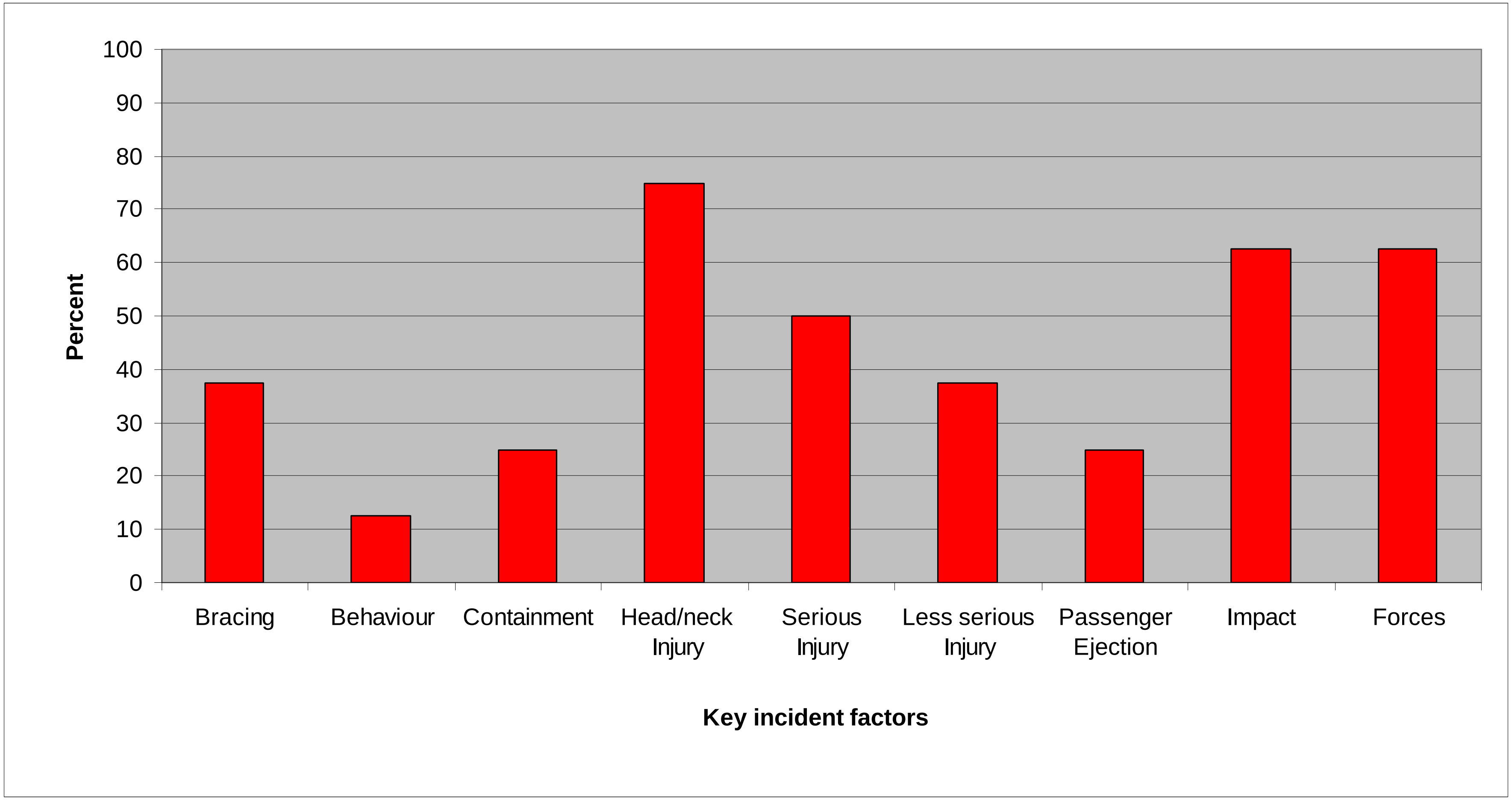
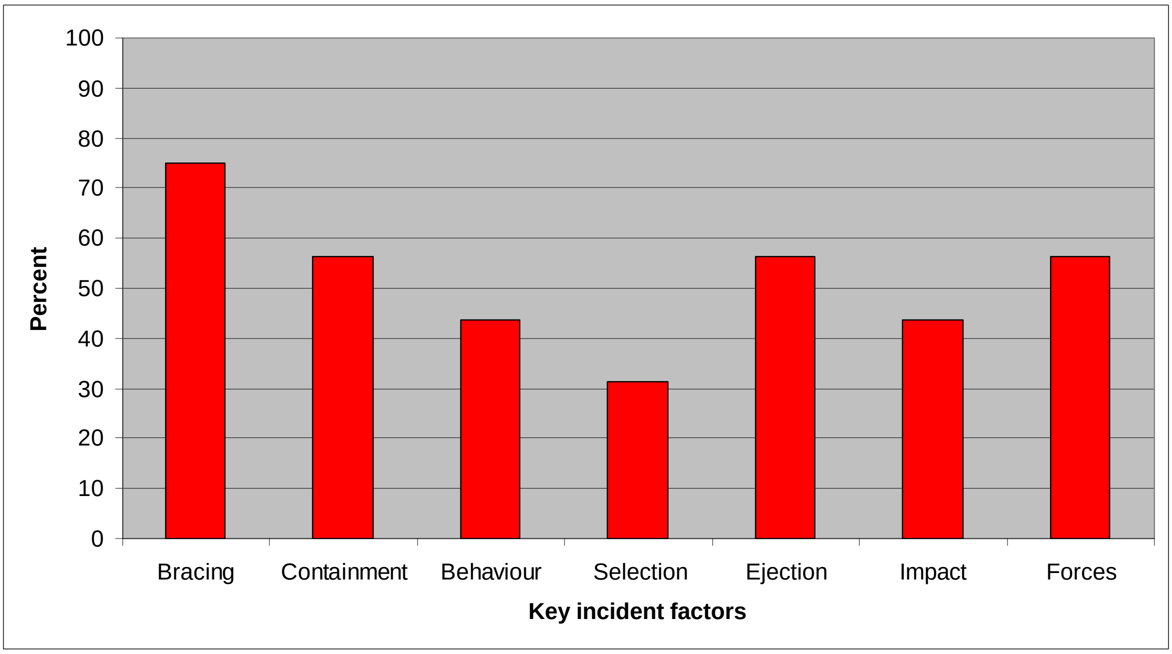


Figure 11. Percent distribution of selected key incident factors for the entries (n=8) that were found to be in violation of the upper acceleration criteria (see table 2).

Inside acceleration criteria from table 2

Eleven and sixteen entries were within the lower and upper acceleration criteria (table 6), respectively.



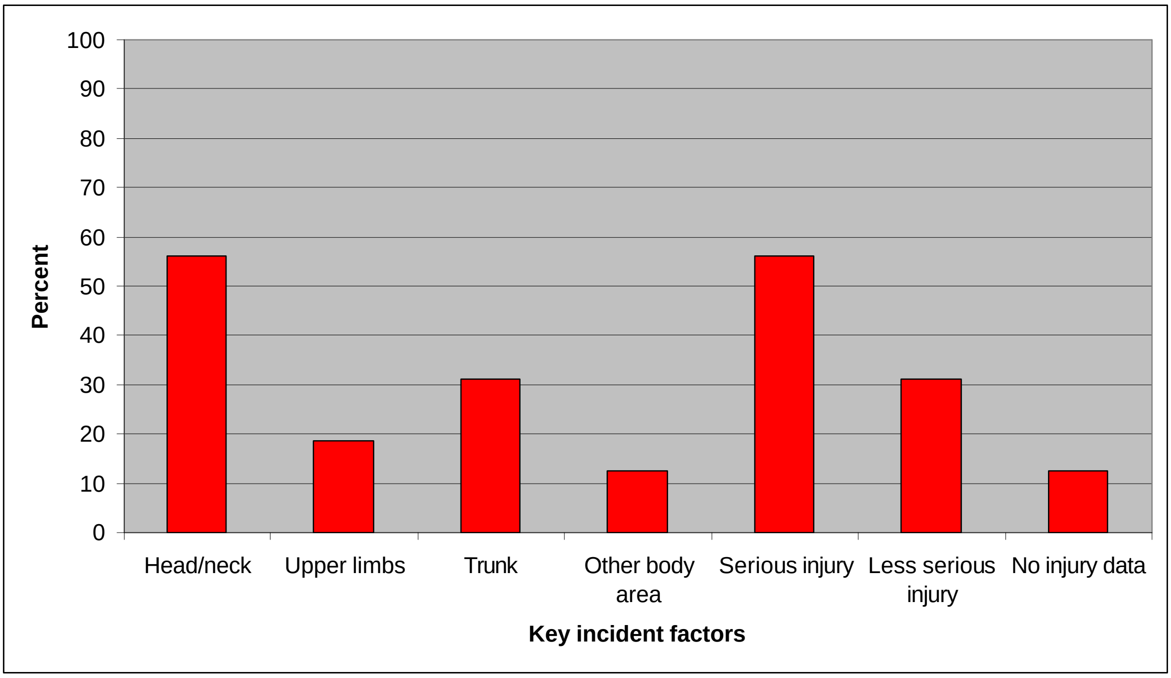


Figure 12. Key incident factors for the entries within the upper acceleration criteria from table 2. The data is expressed as a percentage of the total within the criteria (n=16).

The distribution of key incident factors are shown in figure 12. Head and neck injuries and injuries of a serious nature were common (greater than 50 % of entries). The main injury mechanisms and keywords were bracing (75% of entries), passenger containment, passenger ejection, ride forces (greater than 50 %) and behaviour (greater than 40% of entries).

4.3. Key incident factors query

4.3.1. Keyword descriptors

Table 7. Mean and peak minimum and maximum ride accelerations for the database entries searched by keyword descriptors. Accelerations for the whole database are also shown for comparison purposes.

Keywords	Number of entries	Axes	Mean acceleration (g.)		Peak acceleration (g.)	
			Min.	Max.	Min.	Max.
All database entries	26	X	-1.16	1.72	-3.62	4.24
		Y	-1.62	1.06	-6.24	3.88
		Z	-0.67	3.04	-3.79	6.4
Bracing	16 (62%)	X	-1.21	1.9	-3.62	4.24
		Y	-1.6	1.08	-6.24	2.16
		Z	-0.37	2.71	-1.94	6.4
Containment	13 (50%)	X	-0.93	1.11	-1.52	2.39
		Y	-1.29	0.62	-3.13	2.43
		Z	-0.44	2.96	-3.29	5.78
Forces	15 (58%)	X	-1.4	2.09	-3.62	4.24
		Y	-1.75	1.24	-6.24	3.88
		Z	-0.76	2.85	-3.79	6.39
Operating procedures	9 (35%)	X	-1.11	2.08	-3.62	3.98
		Y	-1.81	1.25	-6.24	2.43
		Z	-0.88	2.33	-3.79	5.63
Passenger selection	9 (35%)	X	-1.44	1.67	-3.62	3.98
		Y	-2.04	1.06	-6.24	2.16
		Z	-0.31	2.81	-1.94	6.4

A high proportion of entries involved bracing, passenger containment and forces, their associated summary accelerations can be seen in table 7.

The mean accelerations were found to be very similar across the keywords (within 0.5 g), compared to the means describing the database as a whole. Examination of the peak values for each keyword emphasised the similarities as several shared the same values.

4.3.2. Body zone injured

Table 8. Mean and peak minimum and maximum ride accelerations for the database entries searched by body zone injured. Accelerations for the whole database are also shown for comparison purposes.

Body zone	Number of entries	Axes	Mean acceleration (g.)		Peak acceleration (g.)	
			Min.	Max.	Min.	Max.
All database entries	26	**X**	-1.16	1.72	-3.62	4.24
		Y	-1.62	1.06	-6.24	3.88
		Z	-0.67	3.04	-3.79	6.4
Head and neck	17 (65%)	**X**	-1.36	1.64	-3.62	4.24
		Y	-1.76	1.02	-6.24	3.88
		Z	-0.52	2.67	-3.79	6.39
Upper limbs	5 (19%)	**X**	-0.98	1.83	-1.59	2.39
		Y	-1.37	1.69	-2.78	3.88
		Z	-0.75	3.57	-3.29	6.14
Trunk	8 (31%)	**X**	-1.35	1.68	-3.62	3.98
		Y	-1.86	1.08	-6.24	2.43
		Z	-0.29	2.95	-2.43	6.39
Other	4 (15%)	**X**	-1.24	1.86	-3.62	3.98
		Y	-2.69	1.02	-6.24	1.26
		Z	-0.07	1.85	-0.2	2.2

Injuries to the head and neck were the most frequent body zones recorded, they were described in 65% of entries in the database (see table 8). Trunk injuries were involved in close to a third of entries.

The accelerations entered in the database were found to be reasonably similar across the body zones and in comparison to the database as a whole. The main exceptions were the Y axis mean maximum acceleration for the upper limbs (1.69 g, this was greater than 0.5 g compared to the rest), and the Y axis mean minimum acceleration for the other body zones (-2.69 g).

4.3.3. *Injury type*

Table 9. Mean and peak minimum and maximum ride accelerations for the database entries searched by injury type. Accelerations for the whole database are also shown for comparison purposes.

Injury type	Number of entries	Axes	Mean acceleration (g.)		Peak acceleration (g.)	
			Min.	Max.	Min.	Max.
All database entries	26	**X**	-1.16	1.72	-3.62	4.24
		Y	-1.62	1.06	-6.24	3.88
		Z	-0.67	3.04	-3.79	6.4
Fatals	3 (12%)	**X**	-1.12	1.34	-1.52*	1.88*
		Y	-1.18	1.12	-1.89*	2.43*
		Z	-0.59	2.88	-1.01*	3.48*
Fractures	7 (27%)	**X**	-1.17	2.12	-3.62	3.98
		Y	-2.46	0.58	-6.24	1.47
		Z	-0.46	2.82	-3.29	5.78
Serious injuries combined	14 (54%)	**X**	-1.17	1.65	-3.62	3.98
		Y	-1.66	0.68	-6.24	2.43
		Z	-0.39	2.84	-3.29	6.39
Less serious injuries combined	14 (54%)	**X**	-1.39	1.98	-3.62	4.24
		Y	-1.91	1.3	-6.29	3.88
		Z	-0.63	2.56	-3.79	6.39

Fatal incidents (n=3) had mean accelerations similar but generally lower than those of the database as a whole. The peak values were considerably lower than corresponding peaks for the other injury types and the whole database (these are highlighted * in table 9).

Incidents that resulted in fracture involved peak accelerations that would in 5 directions have violated the lower acceleration criteria. The means were found to be similar to those of the whole dataset, with the exception of the mean minimum Y axis acceleration (-2.46 g).

Serious injuries involved mean accelerations that were generally lower than the less serious category, despite sharing similar peak values.

4.3.4. Injury mechanism

Table 10. Mean and peak minimum and maximum ride accelerations for the database entries searched by Injury mechanism. Accelerations for the whole database are also shown for comparison purposes.

Injury mechanism	Number of entries	Axes	Mean acceleration (g.)		Peak acceleration (g.)	
			Min.	Max.	Min.	Max.
All database entries	26	**X**	-1.16	1.72	-3.62	4.24
		Y	-1.62	1.06	-6.24	3.88
		Z	-0.67	3.04	-3.79	6.4
Passenger ejection	12 (46%)	**X**	-0.87	1.36	-3.62	3.98
		Y	-1.61	0.64	-6.24	2.43
		Z	-0.09	2.4	-1.01	3.97
Passenger behaviour	8 (31%)	**X**	-0.63	1.47	-1.52	2.39
		Y	-0.82	0.8	-1.89	2.43
		Z	-0.67	2.97	-3.29	5.78
Impacts	13 (50%)	**X**	-1.34	2.07	-3.62	4.24
		Y	-2.01	1.57	-6.24	3.88
		Z	-0.72	3.04	-3.29	6.39
Forces	15 (58%)	**X**	-1.4	2.09	-3.62	4.24
		Y	-1.75	1.24	-6.24	3.88
		Z	-0.76	2.85	-3.79	6.39

A large proportion of entries (table 10) involved impacts and forces as injury mechanisms, the mean accelerations were found to be within the documented acceleration criteria values. In addition, the means compared well with the corresponding values from the database as a whole. Further analysis of the database showed that 10 entries involved both injury mechanisms impacts and forces.

Passenger behaviour was an injury mechanism for 31% of entries. The mean and peak accelerations were notably lower by comparison to the whole data set, impacts and forces.

Passenger ejection accounted for a large proportion of entries (46%), with measured accelerations generally similar to the whole database.

4.3.5. Combination queries

The fatalities

Table 11. Mean and peak minimum and maximum ride accelerations for the database entries from combination searches based on fatal injuries. Accelerations for the whole database are also shown for comparison purposes.

Fatalities with......	Number of entries	Axes	Mean acceleration (g.)		Peak acceleration (g.)	
			Min.	Max.	Min.	Max.
All database entries	26	**X**	-1.16	1.72	-3.62	4.24
		Y	-1.62	1.06	-6.24	3.88
		Z	-0.67	3.04	-3.79	6.4
Passenger ejection AND Passenger behaviour AND Containment	3	**X**	-1.12	1.34	-1.52	1.88
		Y	-1.18	1.12	-1.89	2.43
		Z	-0.59	2.88	-1.01	3.48
Forces	1	**X**	-1.28	1.16	-1.28	1.16
		Y	-1.36	0.69	-1.36	0.69
		Z	-0.21	1.99	-0.21	1.99

All of the entries with fatal incidents involved passenger ejection related to passenger behaviour and associated issues regarding passenger containment (see table 11). The acceleration data for this grouping was generally lower compared to the data as a whole. Forces played a role in one of the fatalities, the actual forces involved would be considered low by comparison to the database as a whole and in relation to the acceleration criteria in table 2.

Passenger ejection and passenger behaviour

Table 12. Mean and peak minimum and maximum ride accelerations for the database entries from the combination search passenger ejection with passenger behaviour. Accelerations for the whole database are also shown for comparison purposes.

	Number of entries	Axes	Mean acceleration (g.)		Peak acceleration (g.)	
			Min.	Max.	Min.	Max.
All database entries	26	**X**	-1.16	1.72	-3.62	4.24
		Y	-1.62	1.06	-6.24	3.88
		Z	-0.67	3.04	-3.79	6.4
Passenger behaviour with Passenger ejection	7	**X**	-0.58	1.34	-1.52	1.9
		Y	-0.82	0.8	-1.89	2.43
		Z	-0.3	2.57	-1.01	3.48

Seven of the entries involved both passenger ejection (n=12, therefore, 58%) and passenger behaviour (see table 12). While 87% of behaviour related incidents resulted in passenger ejection. The mean minimum accelerations were approximately half those noted for the database as a whole. Mean and peak forces were, mainly, lower than those stated in the published acceleration criteria.

Injury seriousness

Most of the head and neck injuries were considered serious (table 13). Less serious head and neck injuries involved higher mean maximum acceleration in the X and Y axes. While the ranges for the Z axis were very similar (approximately 2.9 to 3 g) the less serious neck and head injuries involved a greater mean minimum (-1.29 g), the serious category recorded a greater mean maximum (2.77 g).

The forces were consistent across serious and less serious categories for the other key incident factors (containment, force, impact and passenger selection).

Table 13. Mean minimum and maximum ride accelerations (g.) for the database entries searched by injury seriousness.

Note, when a database entry contained serious and less serious injury types for head and neck injuries they were assumed to be serious.

Incident factors	Axes	Less serious			Serious		
		Min.	Max.	Entries	Min.	Max.	Entries
Head and neck injury	X	-1.35	2.19	4	-1.33	1.49	11
	Y	-1.7	1.39		-1.8	0.58	
	Z	-1.29	1.62		-0.23	2.77	
Containment	X	-1.01	1.17	5	-1.01	0.94	9
	Y	-1.31	0.48		-1.02	0.46	
	Z	-0.36	2.92		0.22	2.4	
Forces	X	-1.49	2.06	7	-1.43	2.12	10
	Y	-1.97	1.41		-1.95	0.95	
	Z	-0.97	2.86		-0.29	2.66	
Impact	X	-1.58	2.18	8	-1.4	2.08	10
	Y	-2.18	1.56		-2.17	1.31	
	Z	-0.45	2.77		-0.81	3.25	
Passenger selection	X	-1.43	1.41	6	-1.81	1.88	5
	Y	-2.36	0.81		-2.15	0.59	
	Z	0.31	1.73		0.21	1.98	

4.4. Stature discrepancy query

Fourteen queries were found to exhibit discrepancies between the operator/manufacturer enforced minimum height restrictions (see table 14) and critical ride dimensions corresponding to human body size data (Norris and Wilson, 1995; Open Ergonomics, 2000).

The critical ride dimensions concerned were related to basic seat design: seat height and seat depth.

Table 14. Actual height restrictions imposed by operators or manufacturers, their associated age related stature and mismatches present for seat pan height and depth. Recommended height restriction calculated using body data and their age related stature is also shown. Note the age related stature data all correspond to average individuals of the age indicated.

Actual				Recommended	
Height restriction (mm)	Age (yrs.) related to stature	Seat pan depth mismatch	Seat pan height mismatch	Height restriction (mm)	Age (yrs.) related to stature
1220	7	✓	✓	1400	10
1200	6	✓	0	1400	10
1400	10	0	✓	1600	14
1200	6	✓	✓	1500	12
1372	10	✓	✓	1450	11
920	2	✓	✓	1200	6
1000	3	✓	✓	1200	6
1280	8	✓	0	1400	10
1066	5	✓	✓	1500	12
1200	6	✓	✓	1500	12
960	3	✓	0	1550	13
1000	3	✓	✓	1330	9
1220	7	✓	0	1400	10
920	2	✓	✓	1400	10

Of all entries exhibiting a stature / height restriction discrepancy in the database 64% involved mismatches in seat depth and seat height. The breakdown of seating mismatches is illustrated in figure 13.

The discrepancies involved age related statures equivalent to that of an average 6 year old. By using the dimensions of the containment components and their associated body part dimensions recommended stature restriction were calculated. The mean recommended stature for this was approximately 1400 mm (equivalent to an average 10 year old). The height restriction mean difference was 200 mm (see figure 14).

The summarised accelerations for the entries are shown in figures 15 and 16. The means were within the acceleration criteria, however, the peak accelerations illustrated violations of the acceleration criteria in five directions.

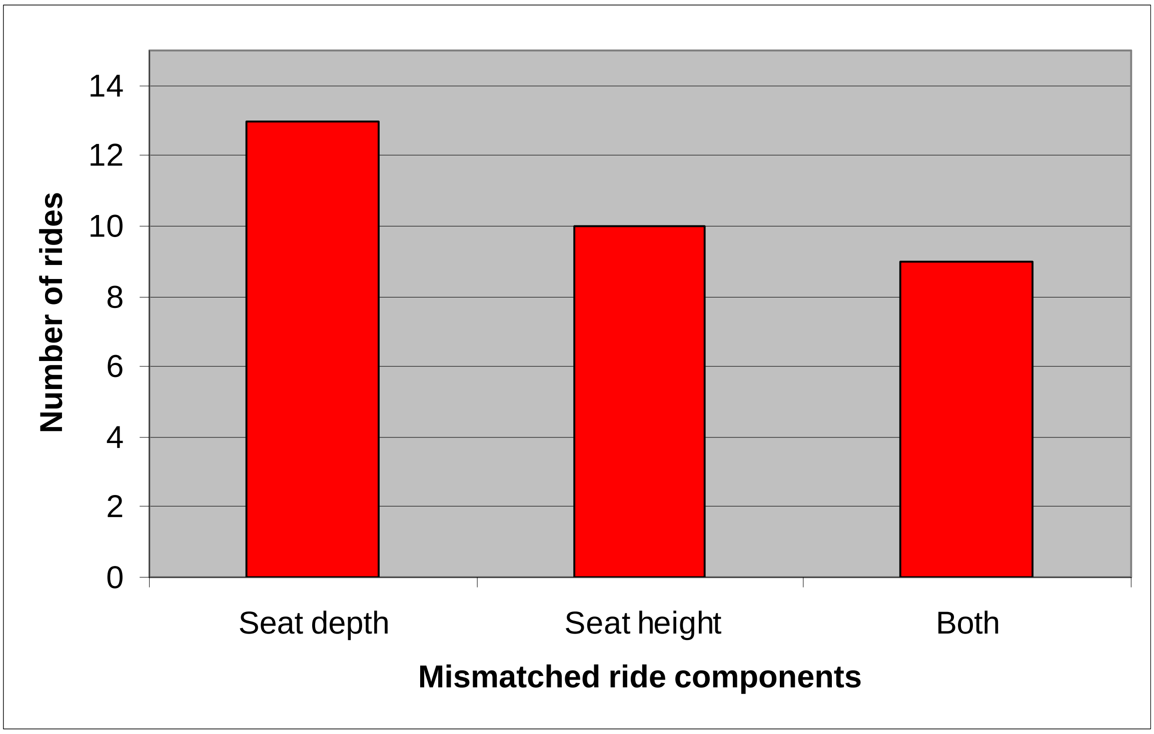


Figure 13. Mismatched ride components for the rides with a stature discrepancy (n=14).

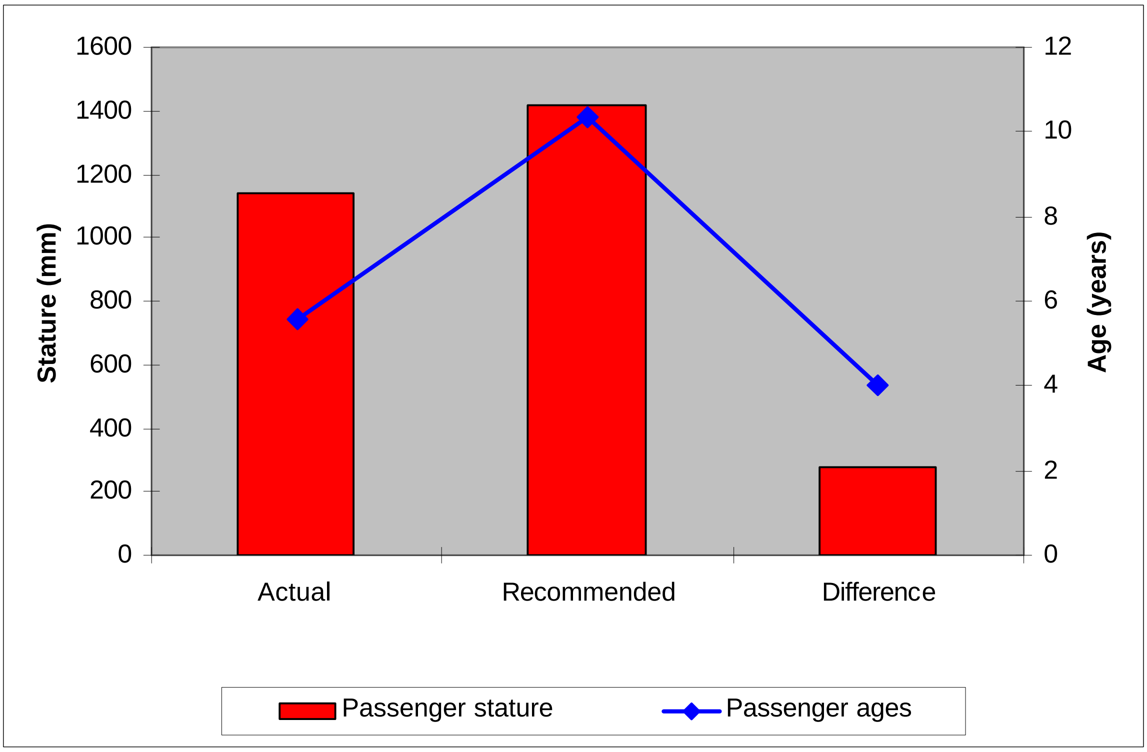


Figure 14. Mean actual and recommended stature restrictions and their related ages (based on average individual data).

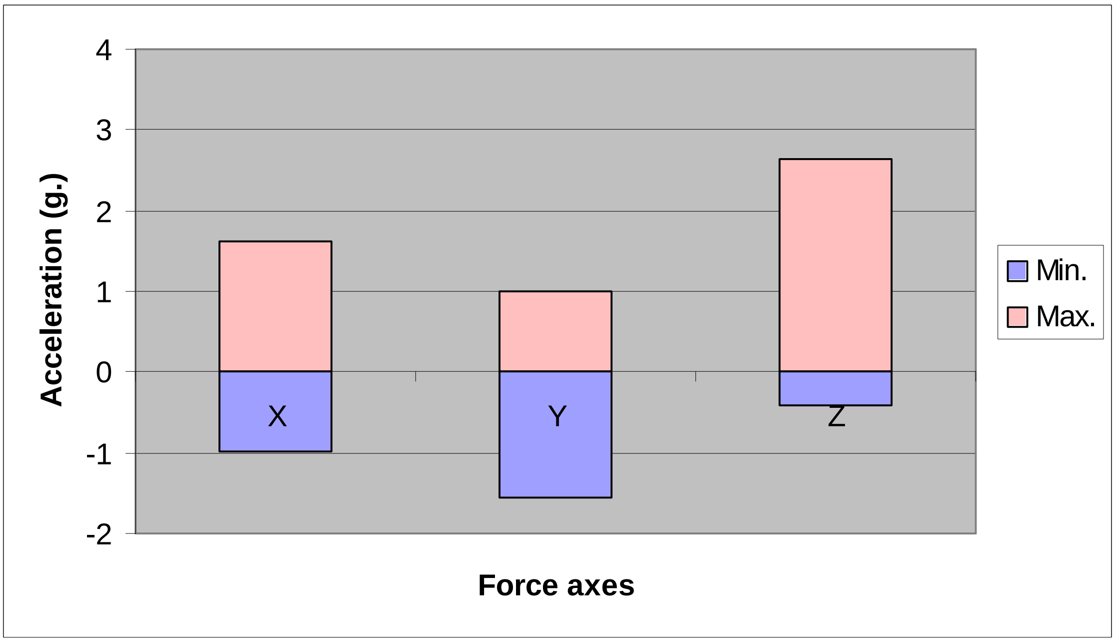


Figure 15. Mean maximum and minimum measured accelerations for the rides (n=14) with a stature discrepancy.

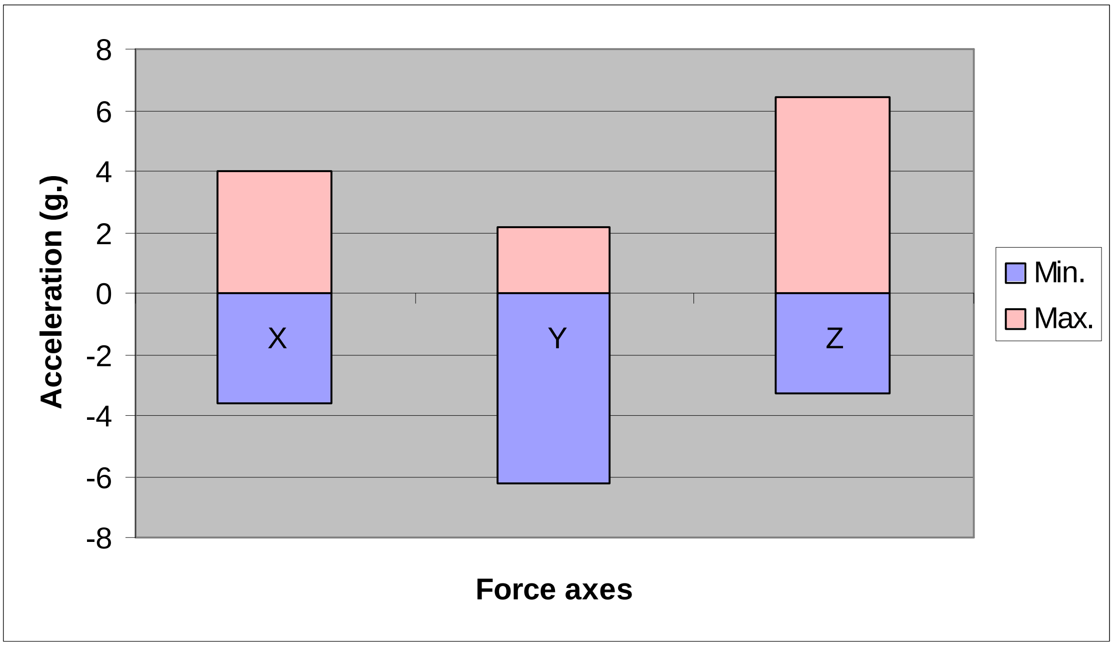


Figure 16. Peak maximum and minimum (illustrating the ranges of) measured accelerations for the rides (n=14) with a stature discrepancy.

5. DISCUSSION

This study only used data collected by the Ergonomics Section at HSL which provided 26 records in the data base. This number can be considered to be a small percentage of the g-force related incidents which may have occurred since 1996. The combination and examination of the incidents as a group is a worthwhile exercise and early on it was felt that important lessons could be learned regarding ergonomics safety on fairground rides. The low number of records limited the statistical inferences that can be made from the results of this study, which was why simple trends and associations were the focus of the analysis. It was recognised that the available data was a snapshot of incidents which may demonstrate trends in the type of accidents which the Ergonomics Section are called in to investigate. It was never the intention to present the results as definitive accident statistics or a measure of risk. There was a feeling amongst the ergonomists involved in incident investigations that there were particular trends in g-force related accidents. The general intention of this project was to identify any such trends which may help in establishing criteria for assessing safe levels of g-force and not to establish safe g-force levels in absolute terms. The basic hypotheses were that the majority of injuries were sustained when g-force levels were within the published limits of human tolerability and that multiple ergonomics factors were related to the incidents. The results of this study suggests that these hypotheses were true. The evidence suggested that certain passenger containment system design criteria were not met. The data interrogation routines were developed to try to identify which these may be.

5.1. Database queries

5.1.1. Ride g-force and passenger containment

There is a general lack of published information regarding safe accelerative forces on passengers of fairground rides. The TUV document goes some way to improve matters but has limitations. The data excludes certain groups at risk, such as pregnant women, people with circulatory or spinal disorders. The concern is that individuals may be unaware of underlying problems and this also relies on a certain amount of suitable screening by ride operators. In addition, no age related information is given, does a child have the same tolerances to accelerative force as an adult? These may be issues that have been addressed in the research, but documentation backing up the TUV publication does not seem to be available. It is therefore, very difficult to comment on the merits of the research underlying the document and the g-force levels specified. For instance, how relevant is a criteria based only on avoiding damage to the cervical vertebrae? It would seem likely that damage to the soft tissues in the neck would occur prior to trauma involving the vertebrae themselves. Damage to the cervical vertebrae would be considered very serious, it could be argued then that protection afforded by allowable g-forces must take account of both the range of tolerances between passengers as well as the onset of less serious clinical symptoms (perhaps even pain / discomfort).

The TUV document only details acceleration in the Y and Z axes (but does take some account of forces applied simultaneously). Presumably, as it is aimed only at allowable limits for coasters, it is assumed that fore/aft (X axis) accelerations are less important perhaps as the passenger would have a tendency to be pushed into the seat. This demands that the passenger containment provides adequate support. However, there are roller coasters which run backwards or that involve the passenger being mounted in a non-standard position (e.g. prone). These factors may alter the relative importance of the axial forces in relation to risk of injury.

The entries with accelerations found to be in excess of the upper acceleration criteria do suggest that the levels prescribed as being the threshold of tolerance for ride acceleration in terms of vertebral injury, are reasonably useful. The high proportion of head and neck injury related to force and impact would seem to bear this out.

The entries within the upper criteria were also often force related but were equally heavily dependent on incident factors such as, bracing, containment and behaviour. These type of factors point to deficiencies in the ride other than excessive forces, which potentially have little to do with individual tolerance to accelerative force and more to do with poor design and associated passenger interaction within a containment system. Forces and impacts were still major factors for entries within the acceleration criteria but it was felt that these were mainly secondary in nature. These factors together emphasise the importance of providing a suitable containment system as well as considering the acceleration the passenger experiences. The TUV document clearly states the need for suitable seats and holding systems for the limit values to be applicable, however, no guidance is provided on what this entails. The design and implementation of a fairground ride should consider static, dynamic and psychological factors to ensure the safety of passengers. In other words there is little value in considering aspects in isolation, when it is a systems approach that is required. For instance, application of low accelerations to a seated passenger may be considered low risk (in terms of physical tolerance to g-force), but relies on the passenger remaining seated (the seat needs to be comfortable, the containment comprehensive and the behavioural aspects need consideration).

The data described in AS 3533.1 was derived from extensive research examining tolerance to g-forces in relation to manned flight and space exploration. As such the participants in the research were typically, selected individuals with an inherent high end tolerance to g-forces (pilots and astronauts). This data would likely over estimate tolerance for the range of passengers using fairground rides, particularly children. Appropriately, the standard only uses the data for information purposes and does not specify limits.

There are limitations in the g-force safety criteria available. Further information is required to ensure any prescribed tolerance levels apply to the majority of potential ride passengers, the levels are based on risks associated with less serious injury symptoms and very importantly, the ride forces are examined in conjunction with other ergonomics issues (the containment system and passenger behaviour / psychology). The evidence from the incidents in the database was that individuals were injured due to multiple factors with the majority of entries describing ride g-forces within currently available criteria. The ride forces may have been tolerable but the containment system was not.

5.1.2. Passenger behaviour

The incidents dealt with in the database demonstrated that passenger behaviour was a major concern. Relatively little is known about the types of passenger behaviour that should be expected on a fairground ride. The age of the passenger may have a part to play but what are the precise factors involved? This and many other questions are important and probably interact with issues surrounding the ride forces. In light of the extreme consequences associated with problems surrounding passenger behaviour (i.e. passenger ejection and a high risk of serious injury - even with relatively low acceleration) it is suggested that further work is required to equip fairground ride designers and operators with the knowledge they require to ensure these aspects are properly addressed.

5.1.3. Fatal incidents

Three of the entries involved incidents that resulted in the death of a passenger. Each of the entries involved relatively low ride accelerative forces, with the passenger being ejected from the ride. Further examination of the relevant HSL reports showed that there were clear actions on the part of the passenger to move out of their seated position. With the passenger out of position low forces can cause passengers to be ejected. There are factors which reduce passengers ability to maintain stability related to the application of unexpected force or a change in force direction. These could include a lack of physical strength or reflexes quick enough to coordinate a suitable bracing response. These **must not** be viewed as weaknesses of the passenger but are due to weaknesses in the containment design which does not fully consider human capabilities. It may have been that the relatively modest forces involved were not sufficient to keep the passenger in their seat (they may not pin the passenger in place or they may be such that the passengers feel ‘safe’ moving around in their seat as the ride progresses). Again, these are issues in the area of passenger behaviour that need to examined.

5.1.4. Bracing

Three quarters of the entries within the upper acceleration criteria had issues related to the passenger’s ability to brace against the ride forces. Again, this relates back to risks associated with forces that would be considered within tolerance limits for passengers comprehensively contained and well supported. However, without the ability to brace (reach and apply force between at least two surfaces - e.g. the foot plate and the seat back) tolerance to force may be reduced and it maybe an individual’s tolerance to impacts within the containment system which better defines the risks and onset of symptoms. Some rides rely more on individual bracing than others and under these circumstances care is needed to ensure passengers can effectively brace against fixed structures and can maintain stability as the ride forces are applied or changed. The provision and positioning of bracing points needs to consider the range of passengers using the ride, particularly as smaller passengers (i.e. children) may find it more difficult to reach bracing points that do not reflect the range of users (these are issues discussed in 5.1.5). Experience from several of the incidents suggested that there are considerable gaps in the literature and knowledge regarding individual ability and capabilities when bracing in such a dynamic environment, particularly, in relation to the wide ranges of passengers that can be accommodated in the fairground setting. Further work is required to help clarify these types of issues, which would also improve knowledge of tolerance to g-forces.

5.1.5. Stature discrepancy

A large proportion (54%) of the database was found to have had minimum height restrictions in place that did not appropriately filter out passengers that would be mismatched to the seats /

containment. Either through short comings of the design process or an inappropriately selected height restriction smaller passengers would be required to deal with these inadequacies. In the cases in the database passengers as young as 2 years old (mean of 6 years old) could have ridden some rides. The large differences between actual and recommended stature restrictions (and how these equate to passenger ages) was considerable. Again, this places passengers at the more vulnerable end of the scale at risk. Indeed, the youngest injured person associated with the database was just 4 years old.

The similarities found between the mean and peak accelerations for the entries with a stature discrepancy and the main data set highlight the fact that suitability of the user population to ride is very important. For many years the fairground industry has used the stature restriction as a means of judging a passengers suitability to ride. Indeed, HSE has published useful guidance in relation to calculating suitable height restriction to aid this process (Thrills Not Spills). Based on the assessments of the database the height restrictions were not all calculated correctly. Clearly, if a ride has a height restriction in place to select suitable passengers it must match the basic seating and bracing requirements of the individual (i.e. the passenger should be sat back in the seat, able to firmly place their feet on the floor or foot rests and be able to comfortably reach any handholds). Very often the only method available to ensure goodness of fit is to inspect passengers once they have entered the ride, as a minimum height restriction is only the first stage of passenger selection.

The evidence suggests that passengers at the smaller end of the population (i.e. children) are at risk as a consequence of setting inappropriate height restrictions. The high proportion of incidents involving factors such as bracing, containment and passenger behaviour emphasise the importance of good design and establishing appropriate operating procedures.

5.2. General

Although the production of the database was to provide the tool by which the aims and objectives of this project could be met, easy access to detailed accident data has been shown to be very effective in identifying trends which may require further investigation. Either the maintenance of this database as an in house resource or the development of a more extensive database for collection and collation of detailed amusement ride accident data should be considered. The cost of in house maintenance would be very small for each individual incident and could be included in the cost of the incident investigation. A more extensive database would require detailed specifications to be drawn up and costed as a separate project.

When considering whether the aims and objectives of the project have been met several factors have to be taken into account. The first objective to set up the data base was achieved and the second objective to update the data in it was achieved also. The delays in the project completion time assisted the second objective but this was only for the duration of the project. There has been no provision made for the resources required to maintain the data base beyond the life span of this project. The third objective has been met in part by assessing the effects of g-forces and associated parameters on those passengers injured in the incidents recorded. However, establishing levels of tolerance for members of the public in terms of g-force will not address the problems identified in this study and is a much larger issue requiring long term research coordination. The majority of the records in the database contain g-force data which is well within what is currently considered to be acceptable limits for amusement rides. It has been suggested that other passenger containment system design criteria, such as relative dimensions of passengers and containment components, fail to take account of what may be considered "tame" ride forces in a way that ensures passenger safety. Until basic ergonomics design principles are applied effectively, it is not possible to establish levels of tolerance for ride g-forces. The most effective route for publication of these results, objective iv, should be the subject of discussion by HSE and the fairgrounds JAC. However, the publication should stress the need for good ergonomics design principles in general not just g-force levels in particular. Objective v deals with the influence these results may have on the development of standards and guidance. Delays in the project end date have missed the opportunity for these results to be considered in the draft of the European Standard on fairground safety. Standards do undergo revision and there may be opportunity at that stage to include items which take account of issues raised by this study. HSE guidance (HS(G)175) has been designed so as to be able to take on board developing knowledge. There should be the opportunity to add suitable advice based on the findings of this study. Once again it is stressed that clear guidance on basic ergonomics design principles and their importance in ensuring passenger safety is needed.

When designing a passenger containment system the question should be 'what is the tolerable limits of the system?' The g-forces imparted by the ride are just one of many human factors issues to be considered when answering this question.

6. CONCLUSIONS

1. A database of incidents investigated by HSL Ergonomists was compiled and found to be a useable tool to review trends and important factors within the data.

2. The hypotheses that the majority of injuries were sustained when g-force levels were within documented limits of human tolerability and that the incidents were related to multiple ergonomics factors was accepted based on the interrogation of the database.

    2.1. Most incidents occurred on rides with measured accelerations within the documented allowable levels of g- forces.

    2.2. The g-forces were still important but were considered to be of secondary importance due to modifying factors related to the ergonomics of the passenger containment system as a whole.

    2.3. The majority of incidents involved ergonomics factors, principally:

        2.3.1. Passenger behaviour.

        2.3.2. Passenger containment design.

        2.3.3. The provision for / ability of passengers to brace themselves.

3. Non application of basic ergonomics design principles was a major feature related to the incident data and the failings were common across a range of ride types. For instance:

    3.1. A large proportion of database entries were found to have stature discrepancies in terms of their height restriction policy.

7. RECOMMENDATIONS

1. The database should be maintained, with the addition of new entries when new investigations are carried out.

2. It may be useful to carry out further reviews of the data:

    2.1 Future comparison to the trends described in the database as it exists currently.

    2.2 When further limit values for ride g-forces are published.

    2.3 When other related guidance is published.

3. Further research is required in the area of fairground safety to help clarify several aspects raised in this report:

    3.1. Passenger behaviour, in particular, with a focus on the behaviour of children on fairground rides.

    3.2. The ability of passengers to brace and so stabilise their bodies as ride forces are applied. This needs to consider :

        3.2.1. The range of passengers (adults and children).

        3.2.2. Their strength capabilities.

        3.2.3. And factors important to the coordination of a suitable bracing response.

    3.3. The tolerability of ride g-forces by passengers. This should take account of:

        3.3.1. The role of other ergonomics factors (such as the ability to brace effectively).

        3.3.2. The variation and ranges of likely passengers (e.g. age and stature).

        3.3.3. The forces associate with less serious symptoms and injuries that can be readily recovered from.

        3.3.4. Definitions of tolerance for containment systems where g-forces are one of many factors to be considered together.

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APPENDIX A. RIDE DATA

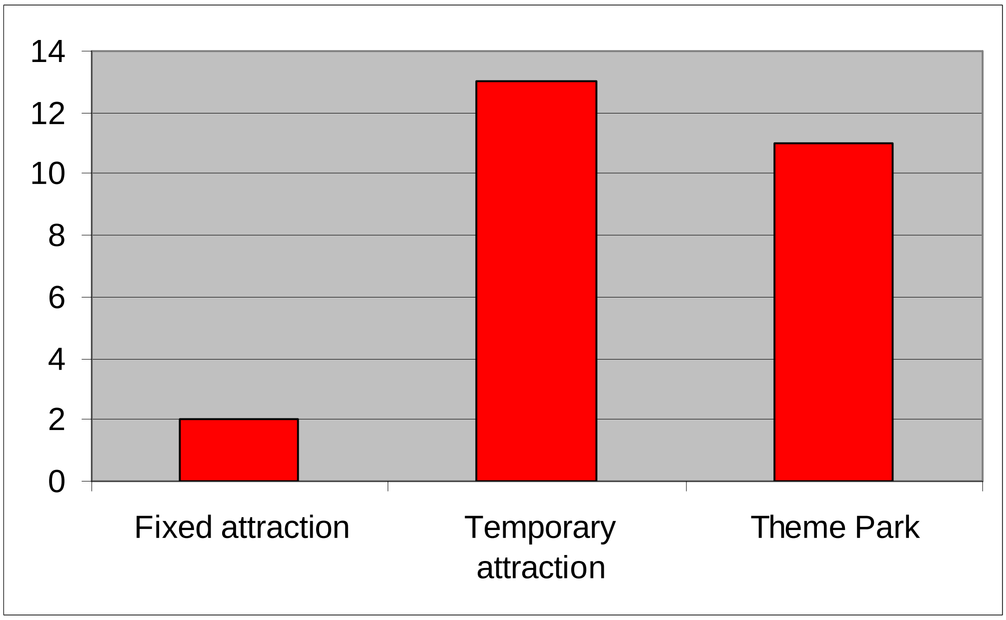

Figure 17. The data set in terms of location site at the time of the ride investigation.

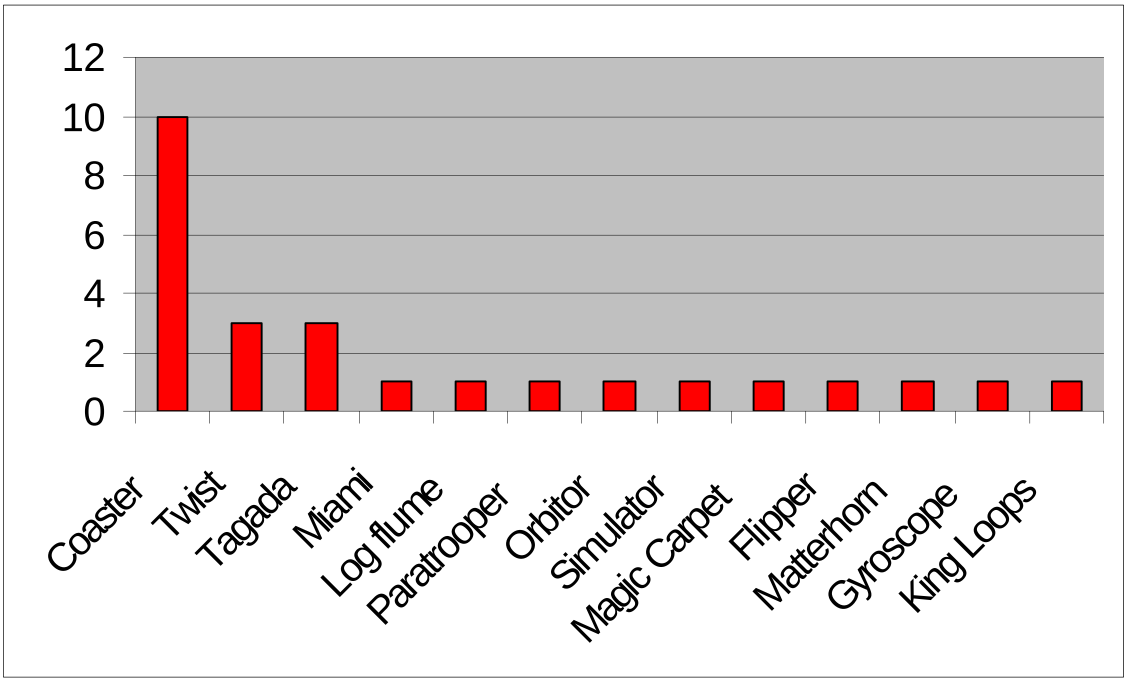

Figure 18. The ride types described in the database.

APPENDIX B. DATA SELECTION SPREADSHEET

Table 15. Spreadsheet of data from HSL fairground incident reports. From which a listing of the data fields used in the iteration of the database was drawn.

Report	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	
1	*	*	*									*	*	*	*	*	*	*					*e	*			*	*	*	*	*	*	*	*	*	*	*	*	*		*	*	
2	*	*	*		*	*	*					*	*	*	*	*	*	*					*e	*			*	*	*				*	*	*	*						*	
3	Report on containment system only																																										
4	*	*	*			*	*	*e		*e		*	*	*	*	*	*	*					*e	*			*	*	*	*												*	Specialised' containment system - extra data fields(?)
5	Task analysis report																																										
6	Report on containment system only																																										
7	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					*e	*			*	*	*													*	
8	Report on containment system only																																										
9	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*					*	*e			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
10	*	*	*	*	*	*	*	*	*	*e	*e	*	*	*	*	*	*	*	*	*			*e	*			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	Specialised' containment system - extra data fields(?)
11	Report on containment system only																																										
12	*	*	*									*	*	*	*	*	*	*					*	*			*	*	*	*	*	*					*	*			*	*	
13	Report on containment system only																																										
14	*		*				*					*	*	*	*	*	*	*	*	*																						*	Age and height not particularly important factors wrt injuries sustained on this
15	*	*	*	*	*			*	*	*e	*e	*	*	*	*	*	*	*					*e	*			*	*	*	*	*	*	*	*	*	*	*	*				*	
16	*	*	*	*	*			*	*	*e	*e	*	*	*	*	*	*	*			*	*e	*e	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
17	A General report?																																										
18	Not relevant to database																																										
19	*	*	*					*e		*e		*	*	*	*	*	*	*	*	*			*e	*			_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	*	r some of the containment values in this report
20	*	*	*	*	*			*e		*e		*	*	*	*	*	*	*					*	*e			_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	*	Specialised' containment system - extra data fields(?)
21	Report on containment system only																																										
22	*	*	*		*	*	*	*e		*e		*	*	*	*	*	*	*					*e	*			*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	
23	*	*	*	*	*	*	*	*	*	*e	*e	*											*	*															*			*	
Totals	14	13	13	7	9	7	8	8	7	6	5	14	13	13	13	13	13	13	3	3	1	1	11	11	1	1	10	10	10	8	7	7	7	7	7	7	7	7	6	4	5	14	

Key to Data in Reports:

1 = Ride type
2 = Location in the country or the world
3 = Theme park or temporary attraction
4 = How many people were injured?
5 = Was the incident fatal?
6 = Classifica& fractured bones.
7 = Classification of body-part(s) injured i.e head or arm
8 = Min age(s) of injured person(s)
9 = Max age(s) of injured person(s).
10 = Min Height.
11 = Max Height.
12 = Containment system tag
13 = Min g in X.
14 = Max g in X.
15 = Min g in Y.
16 = Max g in Y.
17 = Min g in Z.
18 = Max g in Z.
19 = Max rate of change of g.
20 = Min rate of change of g.
21 = Manufacturers suggested Age.

22 = Manufacturers suggested Height.
23 = Operator suggested Age.
24 = Operators suggested Height.
25 = Stature discrepancy: Manufac. vs Operator.
26 = Age discrepancy: Manufac. vs Operator.
27 = Seat back height
28 = Seat pan height
29 = Seat pan depth
30 = Seat back width
31 = Side support height
32 = Side support depth
33 = Seat back to rear edge lap bar - fully closed
34 = Seat back to rear edge lap bar - on latch
35 = Seat pan to lower edge lap bar - fully closed
36 = Seat pan to lower edge lap bar - on latch
37 = Seat back to front edge hand-rail
38 = Seat back to front edge hand-rail
39 = Hand rail diameter
40 = Length of Horizontal floor from seat to front of footwell
41 = Distance from back of seat to front edge of footrest.
42 =QPID performed- Yes / No Tag.

Possible further factors

Single incident or multiple incidents - Related to D1
Additional containment system dimensions and mismatches
Gender of injured person - Related to J1 and K1
Length (time) of ride

Points to raise

Use of data estimation e.g ride age limit from operators height restrictions?
Calculating 'jerk' from the acceleration or g graphs?
Is it OK to estimate minimum age of injured persons by using the operators height restrictions

Additional containment dimensions

Seat pan to top bar height - Shoulder crown
Headrest height - Seated head height
Seat pan to top of main support for lap pad - No dimens given
Diameter of padded suport - no dimensions given
Seat back to trunk support - Chest depth
Between shoulder supports - Head breadth
Shoulder support width - Shoulder length to acromion
Footrest length, seat to footrest - knee height
Seat pan to shoulder supports - Sitting shoulder height
Trunk support length - Sitting shoulder height - (thigh clearance)

APPENDIX C. EXAMPLES OF DATABASE QUERY OUTPUTS

Summary of g-force data

g-force range: 1 to 2

Criteria: Maximum Y

Number of Reports: 7

Key Words

bracing	7
forces	5
operating procedures	4
restraint	4
passenger selection	3
alignment	2

Ride Types

Twist	2
Flipper	1
Matterhorn / Mont Blanc	1
Miami Bench	1
New ride type	1
Roller Coaster	1

Body Parts Injured

Head	3
Face	2
None specified	2
Chest	1
Kidney	1
Lung	1
Neck	1
Right arm	1
Trunk	1

Injury Class

Heavily Bruised	3
Abrasion	2
Fractured Bone	2
Light Bruising	2
None specified	2
Crush	1
Fainting	1
Nausea	1

Whiplash	1
Injury Mechanisms	
Impact with containment component	5
None specified	2
Passenger ejection	2
sustained negative g	1

Summary of Report Details

g-force range: 1 to 2

Criteria: Maximum Y

Ride Name:

Ride Type: Miami Bench

Key words

restraint
bracing
passenger selection

Body Parts Injured	Injury Class	Injury Mechanism
Face	Heavily Bruised	Passenger ejection
Kidney		Impact with containment

Ride Name:

Ride Type: New ride type

Key words

alignment
restraint
operating procedures
forces
bracing

Body Parts Injured	Injury Class	Injury Mechanism
Head	Light Bruising	Impact with containment
	Abrasion	sustained negative g
	Fainting	
	Nausea	

Ride Name:

Ride Type: Twist

Key words

operating procedures
forces
bracing

Body Parts Injured	Injury Class	Injury Mechanism
Right arm	Heavily Bruised	Impact with containment
Trunk	Fractured Bone	

Keyword Summary

Keywords:	behaviour	behaviour
Body Parts:	*	*
Inj. Class:	*	*
Inj. Mech:	Passenger ejection	Passenger ejection
Number of Reports:		7

Ride Name	Ride Type	X Direction Min	X Direction Max	Y Direction Min	Y Direction Max	Z Direction Min	Z Direction Max
	Lifting Paratrooper	-0.02	0.34	-0.01	0.16	0.57	2.34
	Roller Coaster	-1.28	1.16	-1.36	0.69	-0.21	1.99
	Roller Coaster	-0.56	0.97	-1.89	2.43	-1.01	3.48
	Tagada	-0.1	1.6	-0.7	0.7	-0.2	2.2
	Magic Carpet	-1.52	1.88	-0.29	0.23	-0.54	3.17

ANNEX: DATABASE DEVELOPMENT

A. OVERVIEW

For those not familiar with databases, the following explanation of some of the terminology used in this report may prove useful:

- **Record –** a collection of related information stored in the database, in this case a record consists of all the relevant information contained within an incident report.

- **Field –** an individual element within a record, for example the ride type is a field within the above record.

- **Table –** a method of storing the records within a database. Normally a database will contain several related tables.

The database was developed using Microsoft Access 97 due to its versatility, the ability to be installed on 'standard' computers running Windows 9x/NT and the inclusion of Visual Basic for Applications (VBA) as the underlying programming language component. Other considerations included the fact that it is widely available within HSL (and industry in general) and that a database developed in Access can be accessed via the Internet/Intranet should this be a future requirement.

A primary requirement was to make the database as flexible as possible, allowing modifications and the addition of extra data fields when required. It was also important to make the database simple and intuitive to use.

B. DEVELOPMENT PHASES

The database development comprised of three main phases:

- Development of the tables and table relationships

- Development of the graphical user interface (GUI) for data input

- Development of queries and report GUI

Each of these phases are discussed below but it should be noted that in practice the development was an iterative process as the database was constantly evolving as new functionality was required.

Bi. Development of tables and table relationships

The spreadsheet described in section 2.2 (see appendix B) dictated the fields to be included in the database and these formed the main database table. To reduce the risk of input errors and to simplify database interrogation, entries were limited to a selection from a predefined list whenever possible. For example, the ‘location category’ field was limited to a choice from ‘Theme Park’, ‘Temporary Attraction’ or ‘Fixed Attraction’. These predefined lists were stored in separate tables that linked to the main table. The system was designed to be flexible so that the predefined lists could be appended and modified as required.

Another consideration was that of ‘many-to-many’ relationships between fields. For instance, an incident report can have one or more authors and an author can contribute to one or more incident reports. Many-to-many relationships cannot be directly modelled in Access, so an additional ‘linking’ table was required. This also meant that these type of fields did not need to be limited to a maximum number of entries (i.e. there was no limit to the number of authors that can contribute to an incident report).

During the development of the database, additional fields were added as the need became apparent. An example of this was the ‘keyword’ entry, which was not included on the original spreadsheet, but proved very useful when interrogating the database.

During this phase, suitable data types were chosen for each field and where appropriate, sensible limits were imposed upon the fields (e.g. for the injured age fields, the data limits imposed were that a person had to between 0 and 150). Imposing such limits helped reduce the instance of data input errors. Also, it was decided to separate the ‘application’ part of the database from the ‘data’ part, so that the tables were in one file and the user interface and queries were in another. This meant that changes to the application could be made without disturbing the data, which was particularly useful considering the iterative way in which this project evolved.

Bii. Development of the GUI for data input

The second phase of the database development was the design of the GUI to enable efficient and accurate data entry. A GUI is a method of allowing the user to interact with an application, in this case the database, usually using a mouse and keyboard. In the case of Access, this is implemented using a series of ‘forms’, which are displayed on the computer screen. A form typically consists of buttons that the user could activate, text boxes where the user could enter alphanumeric data and list boxes where the user could select an item from a list. As the database was likely to be used on various computers with different screen resolutions, the database forms were designed to fit on a PC with a desktop area of 800x600 pixels, which was the highest resolution that could be easily viewed on a relatively small screen.

The powerful user interface generation tools included within Access were used to create the various forms that the GUI comprised of and, where possible, the GUI was designed to look like a typical Windows application. A priority was to ensure that the system was easy to operate.

It should be noted that the screen shots in this section are for illustration purposes only and display a fictitious data set.

On starting the database, the user was presented with a navigational, or ‘Launchpad’ form, shown in figure 19. From this form, the user could navigate to the other database forms, the main ones were ‘Preview Database Reports’ which is discussed in section Biii and ‘Enter/View Report Data’, which is discussed below.

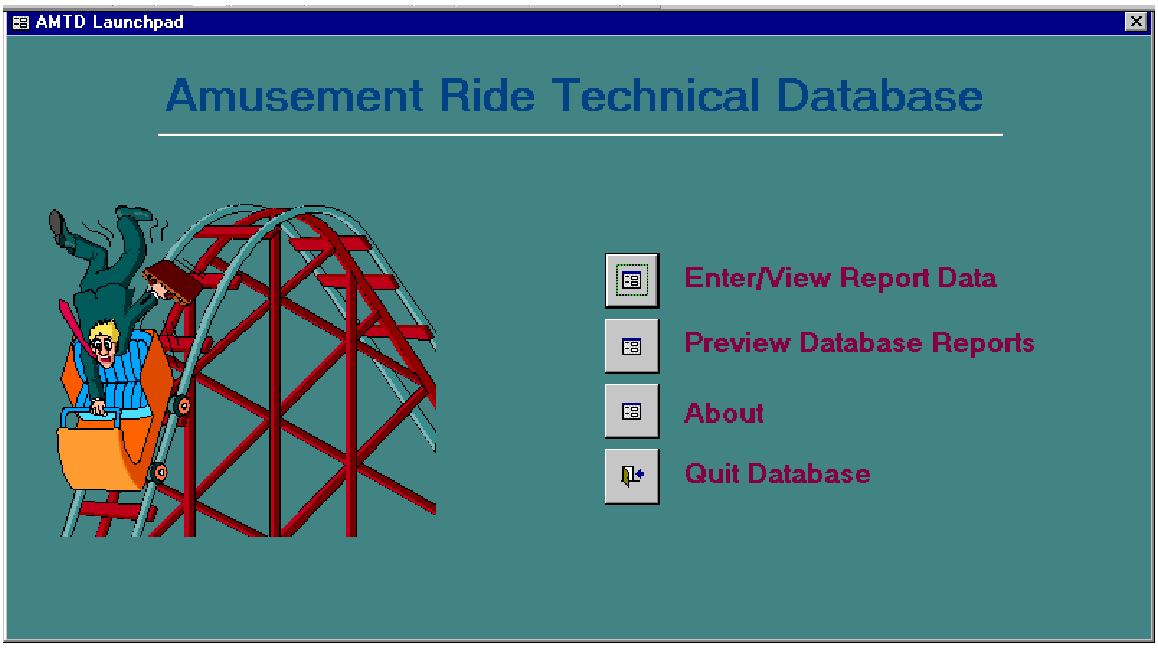

Figure 19. Database main navigational form.

Enter/View report data

This part of the GUI allowed the user to enter data into the database and view or modify existing records. As can be seen from the spreadsheet described in section Bi, there was a large number of fields which would have been impossible to legibly include on a single form. It was therefore, decided to group the database fields into related categories and have a separate ‘mini-form’, or page, for each group. Each page could then be accessed by opening up the main data entry form and clicking on the appropriate ‘tab’, see figure 20.

General details page

This page contained all the general report information including incident report details, ride details and a list of keywords relevant to the current record, and is shown in figure 20. The ‘Ride Type’ was a typical example of limiting the user to choose a value from a predefined list. If the user clicked on the down pointing arrow to the right of the entry, a list of available ride types would be displayed and the user could select the desired type. If the required ride type was not present, the user could double-click on this field which caused a small form to be displayed allowing the user to add a new ride type to the list. This method of using list controls was used throughout the GUI.

The ‘Authors’ field was a typical example of a ‘many to many’ relationship entry described in section Bi above. The user would enter as many authors as required by clicking on the appropriate list and selecting the required author from those that are displayed. Again, if the author was not on the list, it could easily be added.

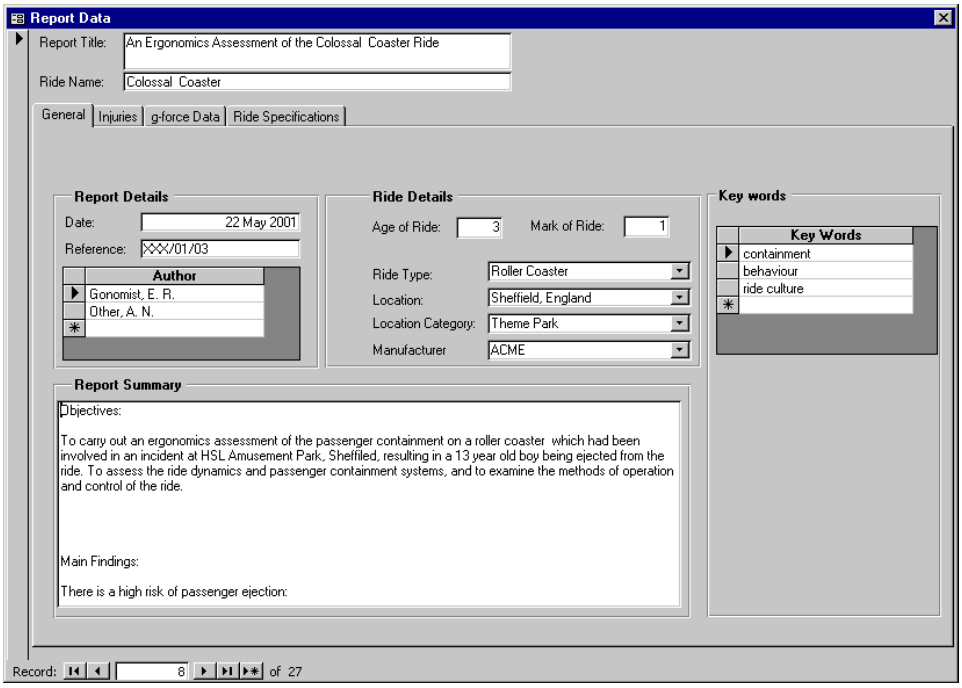

Figure 20. General details page.

Injuries page

This page contained all the information relating to injured parties, including the number of injuries/fatalities, age and height of injured parties, what body parts were injured and how the injuries were caused. An example is shown in figure 21.

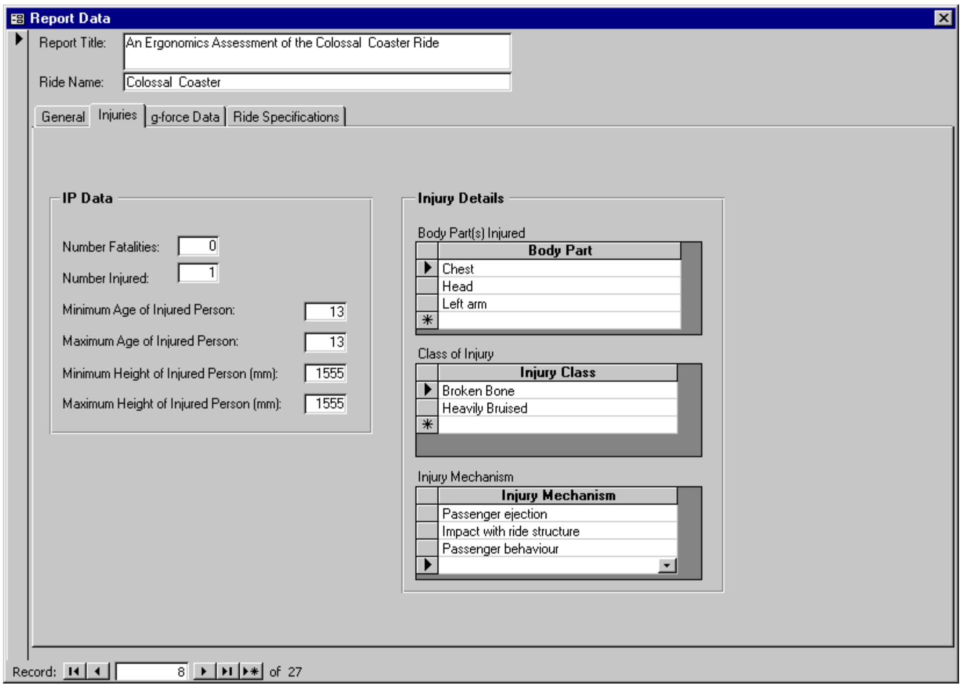

Figure 21. Injuries page.

g-force data page

This page contained all the relevant information related to the g-forces measured and transducer details. An example is shown in figure 22 below. The wire-frame diagram of a person is included as a g-force direction visualisation aid.

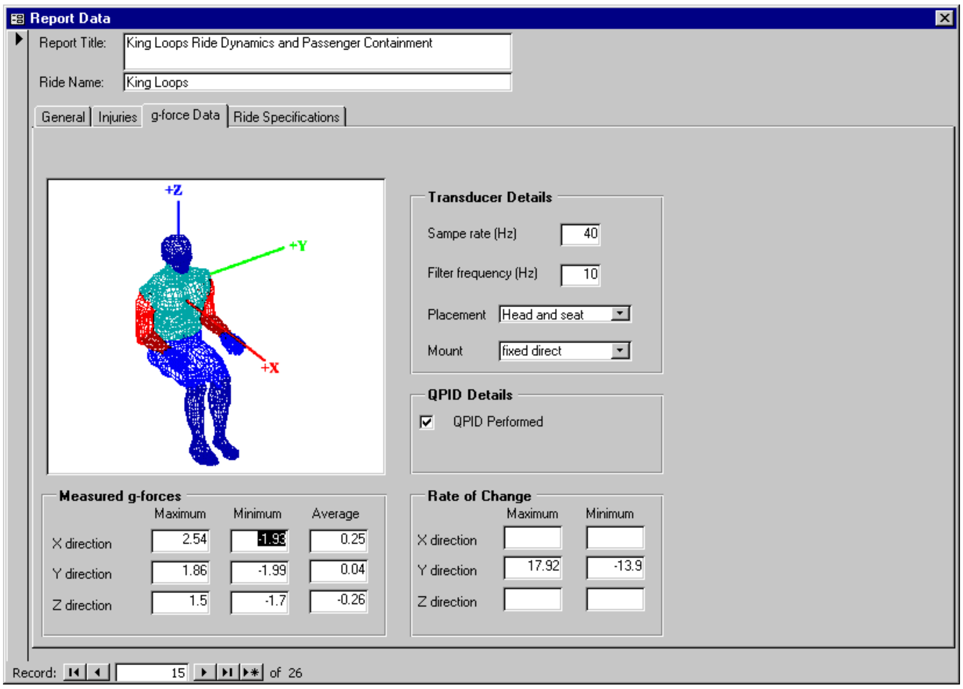

Figure 22. g-force data page.

•Ride specifications page

This page contained information about the containment component dimensions and the suggested age and height of passengers. Because of the number of containment component dimensions, this was again split into groups which could be accessed using the navigational buttons. Figure 23 (a and b) shows examples of these containment component groups. Included on each containment group was a pictorial representation of the dimensions under consideration.

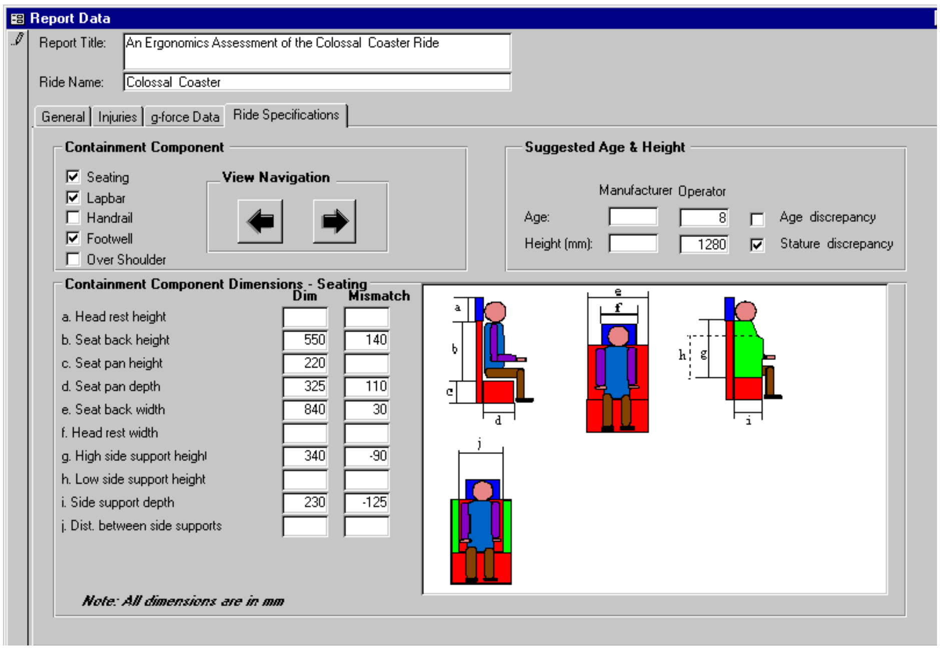

Figure 23 (a). Ride specification page showing seating component dimensions.

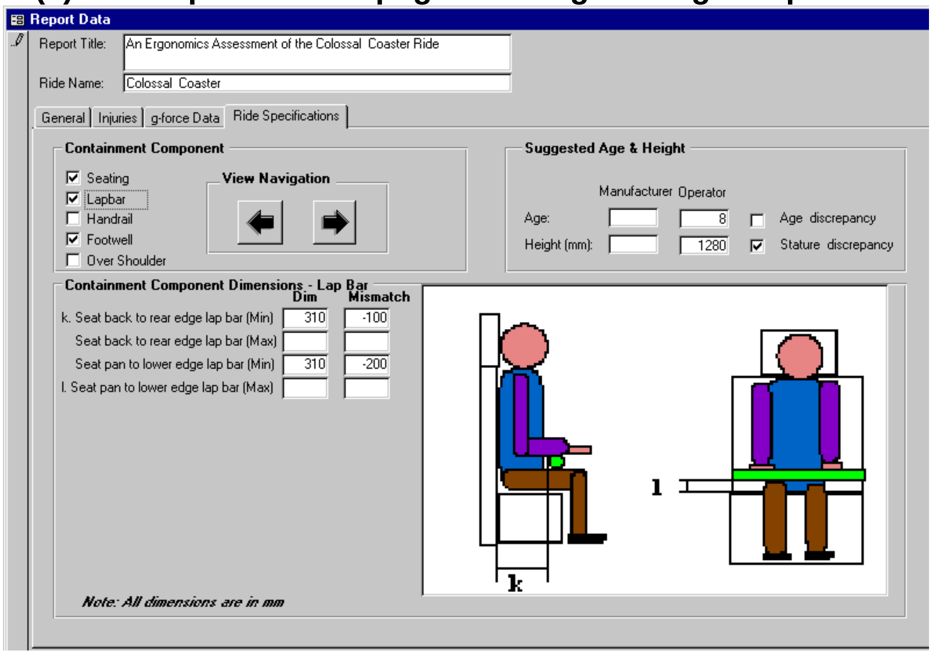

Figure 23 (b). Ride specification page showing lap bar component dimensions.

Biii. Development of queries and report GUI

In order for the database to be used effectively, a method of extracting the required data matching the given criteria was needed. In Access, this was achieved by using a combination of queries and reports. A query is a method of viewing and analysing data within a database and a report is a method of presenting the data in a printed format. In addition, Access allowed the generated reports to be easily exported directly into a spreadsheet (MS Excel) or word processor (MS Word).

The database reports required are described in detail in section 4 but can be categorised as follows:

- Information relating to records with g forces between user specified values in a single axis
- Information relating to records with g forces between user specified values in multiple axes
- Information relating to records where there has been a stature discrepancy
- Information relating to records matching combinations of keywords, body parts, injury class and injury mechanism.

As with the data entry GUI, a priority was to ensure that data extraction was made as simple and flexible as possible without compromising usability. However, consideration was given to the fact that the system was to be operated by an experienced user who was heavily involved in deciding the output required from the database.

The user could access the database reports facility by clicking on the ‘Preview Database Reports’ button on the navigational form displayed on system start-up, see figure 19. This caused the main report preview form to be displayed, see figure 24. (A report preview was a method of viewing the report on the screen as it would appear on paper before actually printing it).

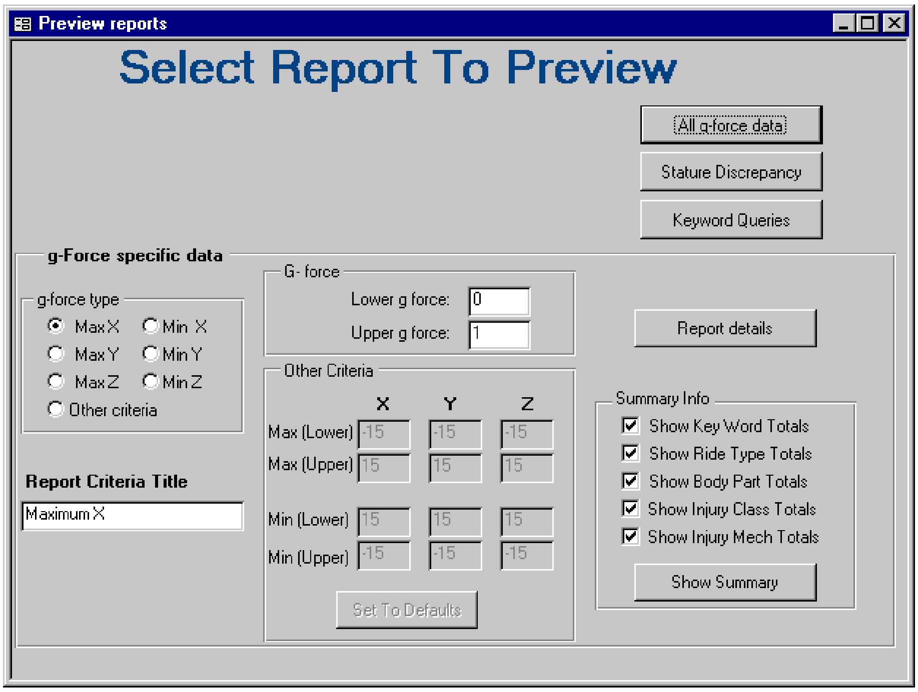

Figure 24. Main report preview form.

In addition to the four types of reports described above, there was a facility to produce a report of all the acceleration data in the database together with ride information. This was accessed by clicking on the 'all g-force data' button, see figure 24.

Single axis acceleration reports

This option allowed the user to interrogate the database for records that lay within specified g-force levels in a single direction. The user selected the g-force direction (X, Y or Z) and type (Max. or Min.) by clicking on the appropriate radio button, see figure 24. Note that the 'Other Criteria' radio button was used for multi-axes reports, (see below). The lower and upper g-forces could then be entered into the appropriate text boxes and the user would then choose to preview one of two database reports, details or summary, which are described below.

- **Details -** This report was activated by clicking on the 'Report details' button, see figure 6. A list of records matching the selected g-force criteria was then displayed detailing the ride name, ride type, all keywords, all body parts injured all injury classes and all injury mechanisms for each incident report.

- **Summary** - This report was activated by clicking on the 'Show Summary' button, see figure 24. A list of the number of records matching the selected g-force criteria would be displayed together with totals of different keywords, body parts, injury classes and injury mechanisms. The user would select what information was included in this report by clicking on the appropriate check boxes in the 'summary Info' area of the form.

Multi-axes g force reports

This option allowed the user to interrogate the database for records that laid within specified g-force levels in all directions (max and min for X, Y and Z). To activate this report, the user first clicked the ‘Other criteria’ radio button which caused all ‘Other Criteria’ g-force level controls to be enabled (un-dimmed). The user would then enter all the g-force criteria for max and min values in the X Y and Z directions. The same reports were available as the single axis reports.

Stature discrepancy reports

This option allowed the user to interrogate the database for all records that had a stature discrepancy and was activated by clicking the ‘Stature Discrepancy’ button, see figure 24. The report generated consisted of a table of ride information (name and type) together with the age and height (actual and suggested) of injured parties and key containment component mismatches.

Key incident factor reports

This option allowed the user to interrogate the database for records that contained specified keywords, body parts, injury classes and Injury mechanisms. To activate this, the user would click on the ‘Keyword Queries’ button, which would cause the ‘Keyword query’ form to be displayed, see figure 25.

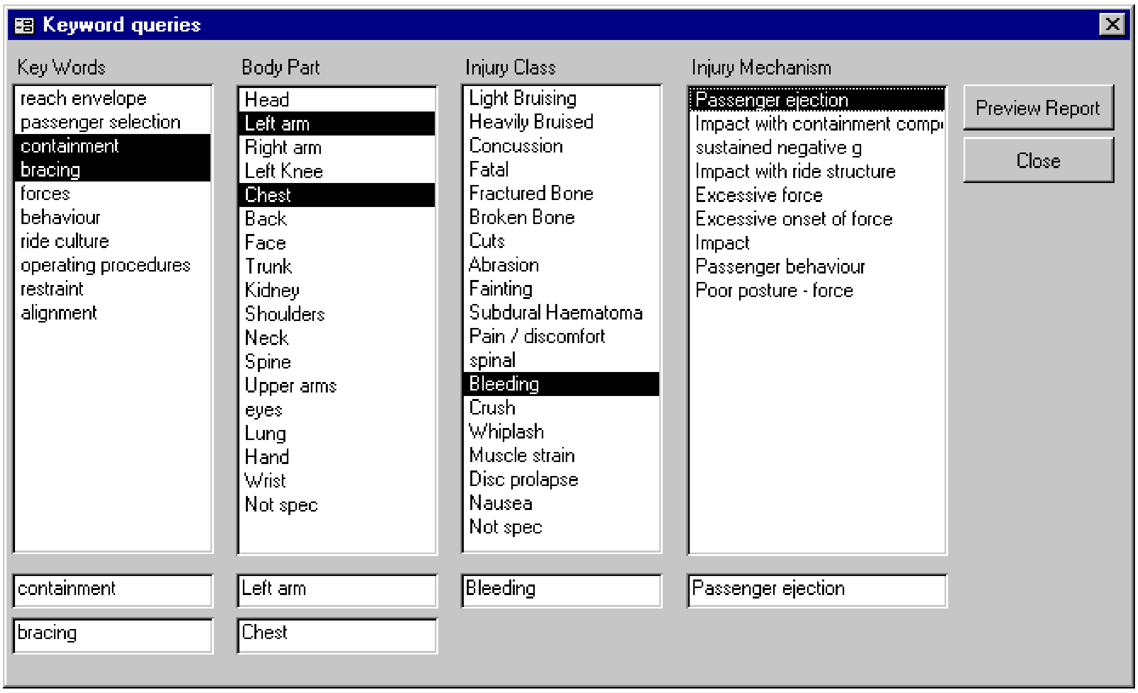

Figure 25. The keyword query form used to search the key incident factors.

The user could select a combination of up to two items from each of the above lists and the chosen items are displayed underneath each relevant list. When the user clicks the ‘Preview Report’ button, the database would be searched for records that match all the criteria selected. The information included on the report consisted of the number of reports matching the criteria, together with a table of the ride name, rides type and associated acceleration data.