HSE
Health & Safety
Executive

Analysis of acceleration data for containment on fairground rides

Prepared by **Health and Safety Laboratory**
for the Health and Safety Executive

CONTRACT RESEARCH REPORT

132/1997

HSE
Health & Safety Executive

Analysis of acceleration data for containment on fairground rides

J A Jackson and T Ward
Workplace Control Group
Health and Safety Laboratory
Broad Lane
Sheffield
S3 7HQ

This paper describes a method developed by the Health and Safety Laboratory for the assessment of amusement ride acceleration data in terms of passenger motion and hence the requirements for the design of passenger containment systems.

Data acquisition techniques are discussed and a standard co-ordinate system is described for three dimensional acceleration data. The interpretation of acceleration time history plots and descriptive statistics gives an insight into the forces which passengers will experience. However, the accelerations need to be resolved into three dimensional vectors to provide useful information for the design of the containment system. A new method of presenting the acceleration data, quadrant analysis, uses plan, side and end view vectors as these are relatively easy to interpret on paper. This method of presenting ride acceleration data allows predictions of passenger motion to be made and hence the requirements of the containment system. The software used for this analysis was a commonly available spreadsheet package running on a PC. A simple method for synchronising on ride video recordings of passengers with the acceleration data is also discussed. The analysis methods are demonstrated using data from a three drop log flume.

These techniques have provided useful information when used to assess existing ride designs and compare rides of similar design. They could equally be applied to data produced by calculation data from a three drop log flume.

This report and the work it describes were funded by the Health and Safety Executive. Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

HSE BOOKS

First published 1997

ISBN 0 7176 1345 3

CONTENTS

1. INTRODUCTION

It is not uncommon for measurements of accelerations to be taken on an amusement ride, or calculated at the design stage. However, for this information to be useful in determining the requirements for passenger containment systems, these accelerations need to be interpreted in terms of the forces exerted on passengers. This paper describes such a method, developed as part of an ongoing research program which aims to develop a set of tools to assist in making ergonomics assessments of passenger containment system designs. The description of the method is followed by a worked example.

2. DATA ACQUISITION

2.1 Instrumenting the ride

A three axis accelerometer and a logging device to record the output over the duration of the ride are required. Accelerometers capable of measuring the acceleration due to gravity when the ride is at rest, such as piezo resistive transducers, are preferable as this is a force which the passengers constantly experience. To obtain the best representation of the ride accelerations experienced by the passengers, the accelerometer should be fixed to the ride seat. A proprietary seat pad accelerometer has been used successfully for this purpose. If the seat to which the accelerometer is attached is sloping, this is not compensated for as any slope will transfer part of the 1g due to gravity into axes other than the vertical. For example on a speedway ride bike, as shown in Figure 1, the bike leans inwards towards the centre of the ride. This will cause a reading other than zero in the lateral axis when the ride is at rest. Also the platform on which the bike is mounted may slope fore and aft transferring a component of g into this axis. The passengers have to compensate for these components so attempting to level the accelerometer on the bike seat would remove some of the information required to understand the forces they experience. A typical arrangement is shown in Figure 1.

It is useful also if an onboard video camera is used to record the reactions of the passengers to the forces they are experiencing. The start of the accelerometer logging needs to be indicated on the video so that the video frames can be synchronised to the acceleration time histories, simple clapperboard techniques have been successful. Small security type cameras connected to portable recorders can be mounted on the rides such that passenger motion can be recorded.

2.2 Data format and acquisition

The data required for the analysis are the ride accelerations, in three dimensions, imposed on the passengers. To measure these on an existing ride the output from a three axis accelerometer needs to be logged against time. The convention used for the three dimensional axes is +X to the front of the passenger unit , +Y to the right of the passenger unit and +Z upwards. As we are using Piezo resistive transducers, there will be a +1g offset in the Z axis due to gravity when the seat in the passenger unit is horizontal. The accelerations we are interested in are those which may cause movement of the passengers or require them to brace themselves. Acceleration information at frequencies up to 10Hz, by analogy with whole body vibration frequencies, need to be recorded. To obtain reliable data, this requires a sampling frequency of 40Hz with the acceleration signals being passed through a 10Hz low pass filter. The resultant data will give X, Y and Z axis values, which can be calibrated to read either m/s^2 or g, with respect to time for a normal ride cycle. It should be remembered that the loading of the ride i.e. the number and distribution of passengers, can effect the ride dynamics. It is convenient to produce data files in ASCII format as this allows the files to be imported into almost any spreadsheet type software package.

In order to synchronise the video recordings with the acceleration data, the start of logging mark on the video is taken as time zero. This can be read directly from a time elapsed counter on a video player front panel with the timer being reset at the start of each test. A more effective method is to produce a copy of the video recordings with an in vision time code which is reset to zero at the start of each test.

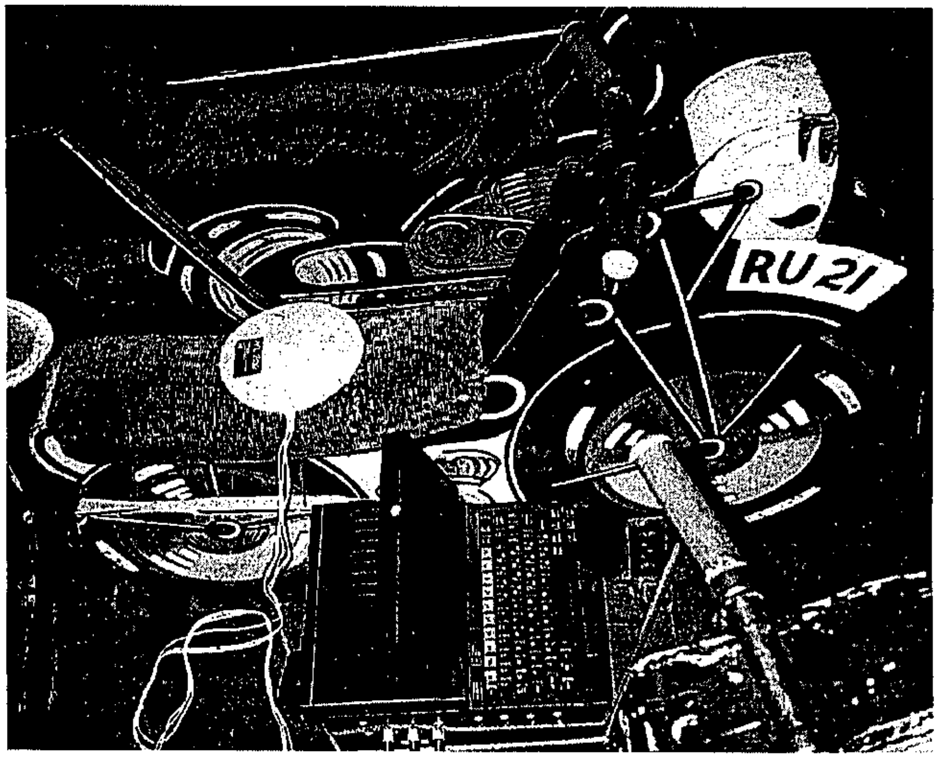


Figure 1. Seat pad accelerometer and logger installed on speedway ride

3. RIDE ACCELERATION DATA ANALYSIS

3.1 Statistics

To assess an individual ride it is useful to generate descriptive statistics of the acceleration time histories e.g. maximum, minimum and mean for each axis. Maximum and minimum accelerations will help identify peaks whereas the mean acceleration may give some indication of any offset. When comparing one test result with another or one ride with another correlation routines may be used. However, statistical information on its own is of limited use and more detailed consideration of the data is necessary in order to address containment issues.

3.2 Acceleration time histories

Acceleration time histories are plots of ride accelerations against time for the three axes. These give an overall impression of the dynamic profile of the ride. They may indicate specific events where the accelerations are highest or rapidly changing. These areas of specific interest may be expanded, by changing the time axis intervals, for more detailed analysis. It is important to plot all three accelerometer outputs on the same graph in a way in which they are distinguishable. Colour monitors and / or printers can achieve this.

To understand what is happening on an acceleration time history plot it is essential to know what the peaks and troughs represent. Figure 2 shows one axis of the accelerometer starting at rest, accelerating, attaining a steady speed, decelerating and coming back to rest.

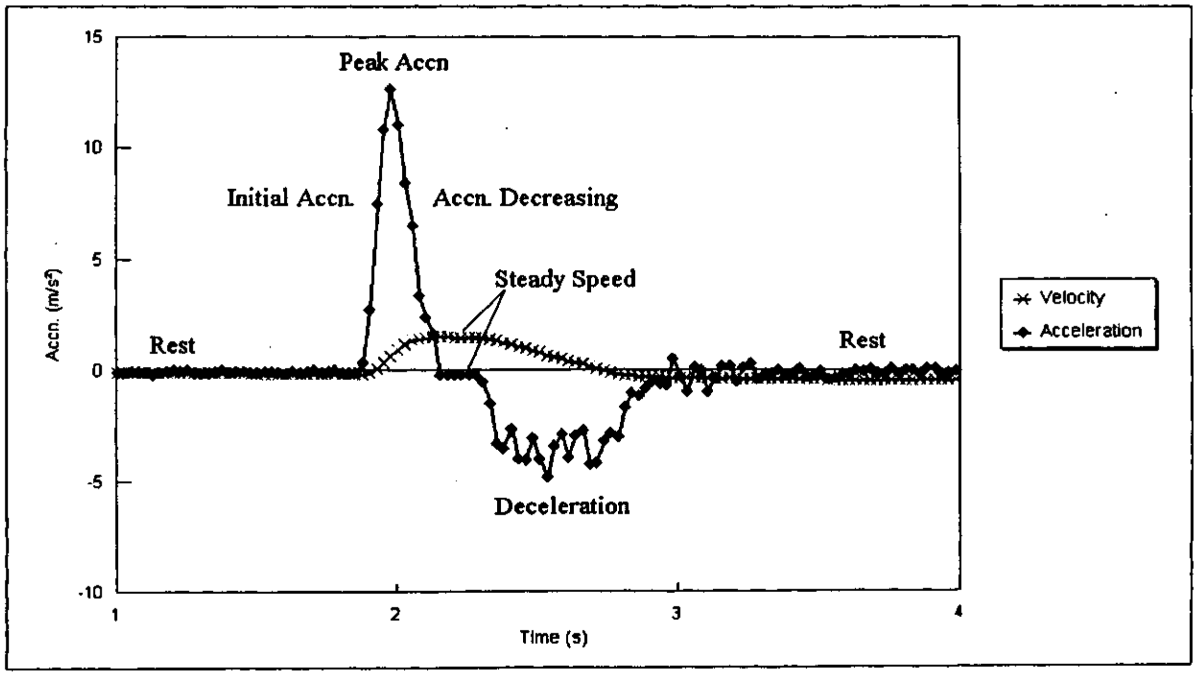


Figure 2. Accelerometer output.

Contents

After the peak acceleration, at around 2 seconds, the acceleration values start to decrease. This is often misinterpreted as deceleration when in fact the ride is still getting faster but at a lesser rate. Deceleration only occurs after the acceleration has dropped below the level representing steady speed.

Analysis will concentrate on the direction of acceleration using the conventions set out above. However, some confusion can arise when associating direction of ride motion with direction of ride acceleration. A rollercoaster car under braking will still be moving forwards but the accelerations will be -X ie. backwards. It is the acceleration force which the passengers will react to so the direction of ride motion can be mostly ignored.

When used in conjunction with synchronised video recordings, acceleration time history plots can be used to identify periods of high ride forces, rapid changes in acceleration magnitude or direction and periods where there may be concern over the extent of passenger movement. However, it is still difficult to visualise what is happening in three dimensional space. In order to gain a fuller understanding of ride forces and hence the requirements of the passenger containment system we need to consider ride accelerations and passenger reaction forces as three dimensional vectors.

3.3 Quadrant analysis

Although acceleration time histories can be plotted with all three axes on the same graph it is still very difficult to work out what is happening in three dimensional space. If the time component was to be retained a four dimensional vector plot would be required which is almost impossible to represent on paper. Two dimensional representations of three dimensional plots can also be very difficult to interpret. An analysis technique which uses three two dimensional plots, known as quadrant analysis, has been developed by HSL.

Quadrant analysis does not present time information graphically. Either the whole ride cycle is plotted, though this can result in a very confused graph, or a specific event period is identified and plotted. It is often useful to include the time period for the plot in the graph title. Quadrant analysis works by plotting the accelerations in one axis against those in another to produce graphical representations of accelerations in the plane containing both axes. X values are plotted against Y values to produce a plan view of the ride motion, Z values are plotted against X values to produce a side view and Z values are plotted against Y values to give the end view. The graphs are arranged such that they are divided into four equal quadrants with the axis origin at the centre. If all three graphs use the same axis scale, comparisons of acceleration magnitude can be made more readily. By observing in which quadrant the accelerations take place, the direction of ride accelerations in each plane can be described. The direction descriptions for each plane are shown in Figure 3.

Contents

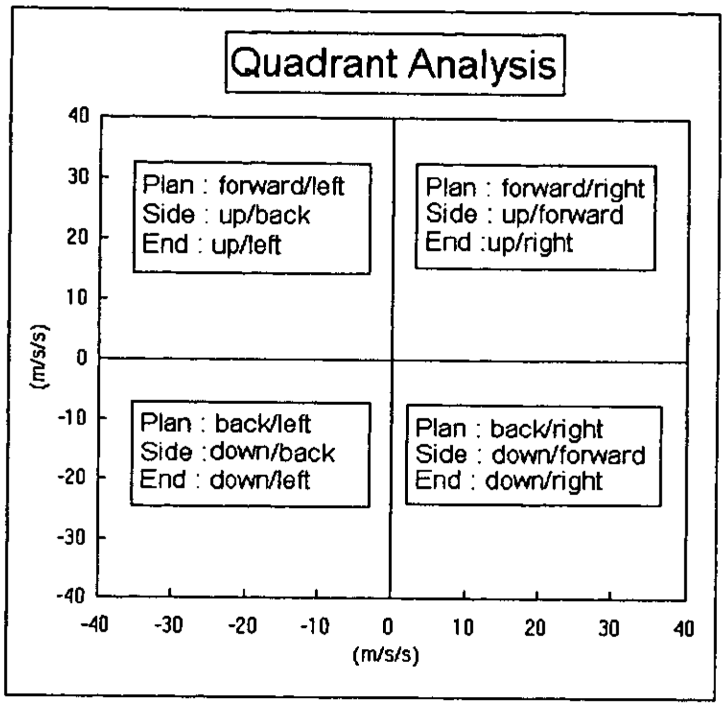


Figure 3. Quadrant plot direction of ride accelerations

To give an example, in the plan view accelerations in the top left quadrant would be in a forward and left direction. In the side view accelerations in the upper right quadrant would be in an up and forward direction. In the end view accelerations in the upper left quadrant would be in an up and left direction. Combining these three descriptions of the direction of ride accelerations gives forwards / up / left as the predominant direction of the vector in three dimensional space. The ride accelerations may occupy more than one quadrant which leads to multiple descriptions which may be qualified by giving approximate percentages of the plot in each quadrant.

4. PREDICTION OF CONTAINMENT REQUIREMENTS

The analysis thus far has provided information on the size and direction of ride accelerations. To predict the requirements for the design of the passenger containment system, we need to interpret these results in terms of the directions in which the passenger requires containment.

What the passengers will experience will be the reaction to the ride accelerations and gravity. At rest the passengers experience a force down into the seat of 1g (on a non sloping seat) due to gravity which will appear in the ride acceleration data as +1g in the Z axis. The time history and quadrant plots would show this as an upwards vector. The effect experienced by the passenger is to be pushed down into the seat. If we consider a ride acceleration of -2g in the X axis, a backwards vector according to the plots, the passengers will actually experience forwards motion of the body. Therefore, to interpret the three dimensional ride vector descriptions derived from the quadrant analysis in terms of passenger containment requirements, we have to reverse the directions. For example, a ride vector of forwards / up / left would result in passengers experiencing motion in a backwards / down / right direction.

From this the implications for the design of the passenger containment system can be derived. If the passengers are experiencing backwards / down / right motion then the containment system has to provide support in that direction eg. a seat with a sufficiently high backrest and lateral support to the right of the passenger.

In many cases the ride accelerations are changing size and direction frequently and these changes will make different demands on the containment system at different times. Some rides have a simple dynamic profile such as the log flume type rides. Here the drops produce discrete dynamic events with little action in between.

5. CASE STUDY : LOG FLUME TYPE RIDE

5.1 Introduction

To illustrate the techniques the results from measurements taken on a three drop log flume type ride will be presented. Although only the dynamics will be discussed, other factors also need to be taken into consideration when making an assessment of the containment system (Jackson, 1995). On log flume type rides there are many factors which can affect the magnitude of the accelerations but again these will not be discussed here.

5.2 Data acquisition

To measure the accelerations on the ride a three axis seat pad accelerometer was attached to the seat of the boat and the data was collected on a digital logging system which was also secured in the boat. The arrangement of the instrumentation is shown in Figure 5. The data were logged at 40Hz with a 10Hz low pass filter. The data were imported into a spreadsheet for analysis.

Figure 5. Equipment installed in boat

5.3 Data analysis

5.3.1 *Statistics*

The maximum, minimum and average accelerations were calculated for the whole ride cycle. The results are given in Table 1. The maximum values represent the highest acceleration in the positive direction on each axis and the minimum values the highest acceleration in the negative direction on each axis. Without the time history associated with these measurements we do not know where they occur but they do give us an idea of the range of forces experienced by the passengers in each direction.

Table 1. Log flume acceleration statistics (m/s^2)

	X axis	Y axis	Z axis
MAX	6.32	5.39	21.8
MIN	-7.62	-3.6	2.83
AVG	0.73	0.01	9.92

5.3.2 *Acceleration time history plots*

The acceleration time history shows three distinct events, one for each of the drops. The periods between these events show little or no dynamic activity so we can concentrate on the three drops. For the purpose of this report only one drop will be looked at in detail as the analysis technique would be the same for all three. The plots for the whole ride and one of the drops are shown in Appendix A.

Looking at the whole ride cycle, there is an increase in the X axis and a corresponding decrease in the Z axis just before each of the peaks. This is the period when the boat is on the pull up section of the drops. The changes in the X and Z axes are due to the seat pad accelerometer changing position with respect to gravity and hence a component of g moves from the Z axis to the X axis. There are very minor fluctuations in the Y axis which are probably due to the boat banging against the sides of the water trough on the curves.

The time history for the third drop concentrates on the splash event. The Y axis can be ignored as there is little or no activity in that direction. The Z axis shows a slight dip below 10 m/s^2 (around 336 s), at which point the passengers would tend to feel lighter. This is then followed by a rapid rise to just over 20 m/s^2 (around 338 s) which would act to push the passengers down into the seat. As the rate of acceleration in the Z axis is decreasing, there is a sharp negative peak in the X axis which indicates that the boat is decelerating. By the time the negative peak in the X axis starts to subside, the acceleration in the Z axis has levelled out at fractionally above 10 m/s^2.

The above analyses give us a very detailed description of the ride dynamics and some insight into the forces experienced by the passengers.

5.3.3 *Quadrant analysis*

Quadrant analysis could be carried out for each of the dynamic events, in this report we will concentrate on the third drop which occurs between 333 and 343 seconds. The quadrant analysis plots are shown in Appendix B.

Taking the plan view, Figure B1, the accelerations are all in the negative X direction with accelerations in the Y axis either side of the zero line. Hence the description of the ride acceleration vector in this plane would be backwards. In the side view, Figure B2, the accelerations are in the upper left quadrant which gives backwards / up as the description of ride acceleration vector in this plane. In the end view, Figure B3, the accelerations are in the positive Z direction with no significant lateral accelerations. The resultant three dimensional description of ride acceleration vector is backwards / up / no sideways.

5.3.4 *Prediction of containment requirements*

The descriptive statistics tell us that the maximum accelerations experienced by the passengers is around 2g vertical, 1g horizontal and 0.5g lateral. These would not be considered excessive. The acceleration time histories tell us that the passengers only experience significant forces on the drops. Looking more closely at the drops tell us that the passengers will experience the Z axis accelerations fractionally before the X axis ones. The quadrant analysis gave a three dimensional ride acceleration vector description of backwards / up / no sideways, therefore the passengers would experience motion in a forwards / down / limited sideways direction.

This analysis shows that passengers need facilities in the containment system to cope with their tendency to experience movement downwards and forwards. These facilities could include restraints or, given the relatively low forces, bracing points.

6. DISCUSSION

The method presented here uses only ride data to produce graphs and tables in order to predict passenger motion. When making an ergonomics assessment of a passenger containment system there are three main factors to consider; static factors - the relationship between body size and containment system dimensions; dynamic factors - the effects of ride forces on passengers; psychological factors - passengers' perceptions of the ride and their behaviour (Jackson, 1995). In the past video was used for both the dynamics and the psychological factors. The new methods presented here do not mean that the use of video recordings to provide information about passenger movement should be discontinued. It is a good idea to use video recordings along with the objective measurement of ride accelerations especially if the video can be synchronised to the acceleration data This can help to visualise where passengers may have problems and trace these points in time back to the acceleration values.

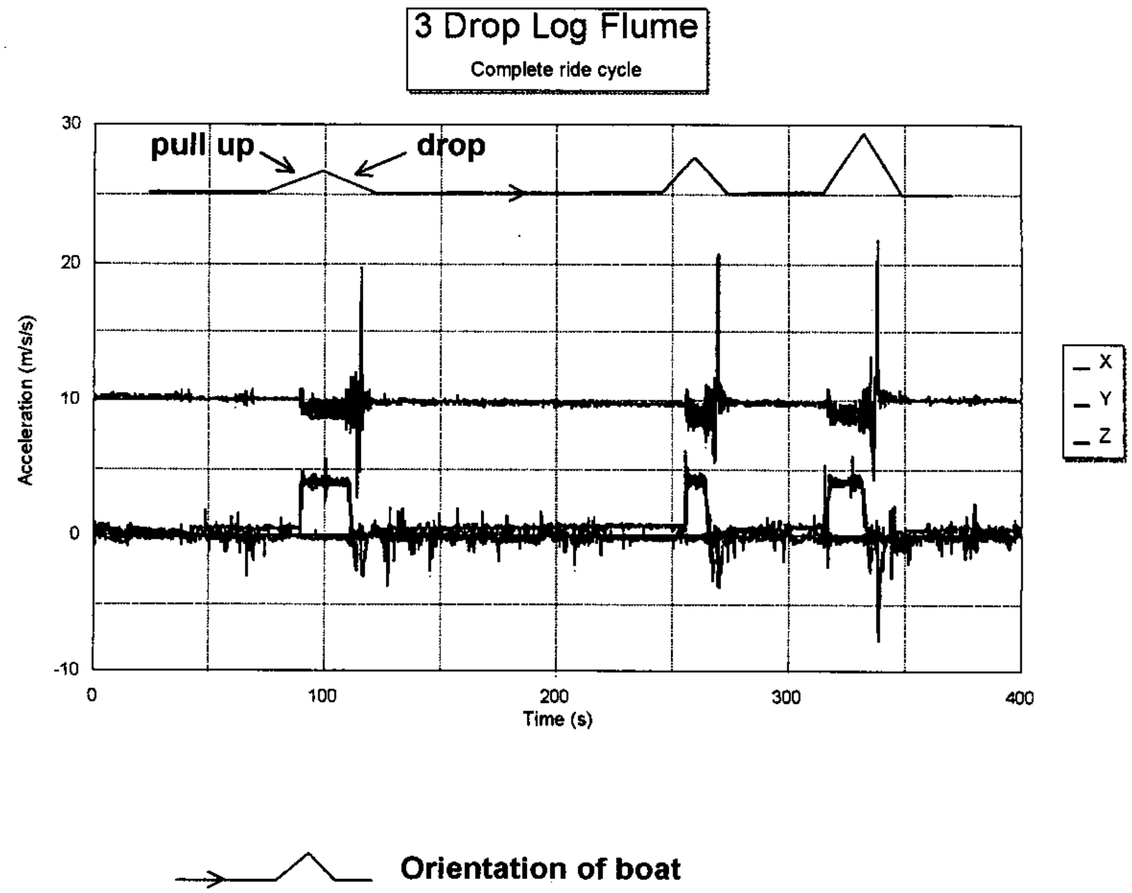
7. CONCLUSION

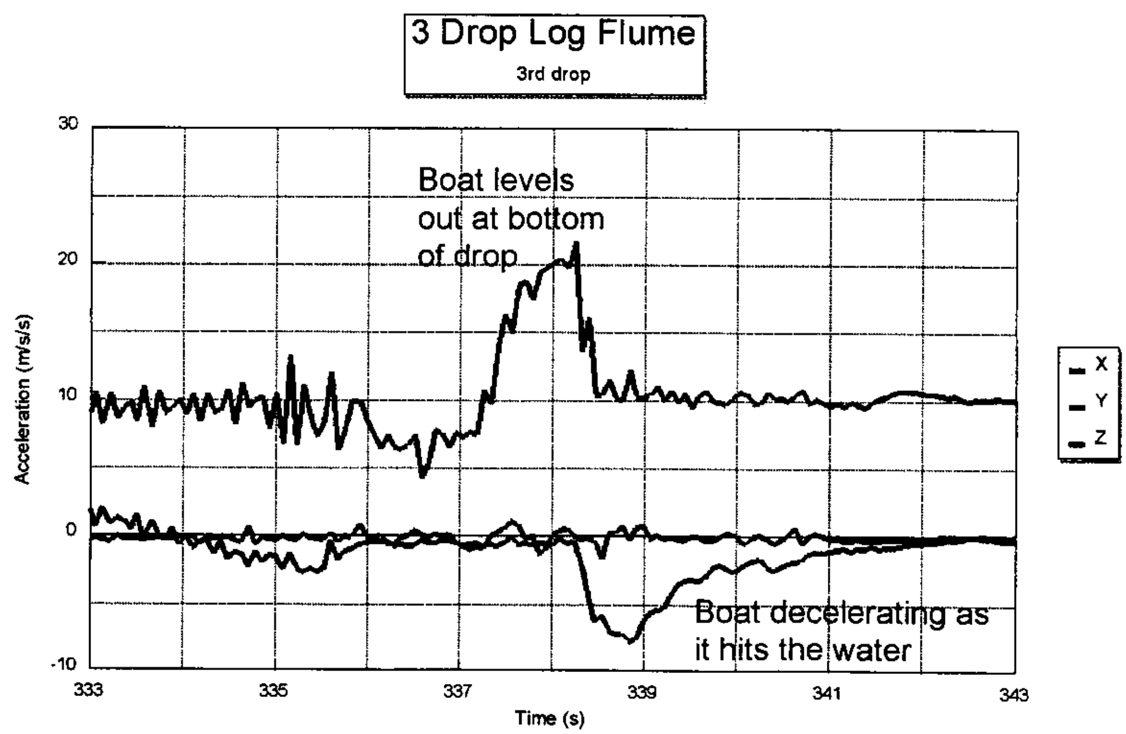
The methods presented in this report have proved effective when used to evaluate the dynamics on existing rides. However, a full ergonomics evaluation of a containment system is required if the design is to be effective in ensuring the safety of the passengers.

8. REFERENCE

Jackson, J.A., 1995, Ergonomics assessment of containment on fairground rides, Contemporary Ergonomics 1995, ed. Robertson, S.A., Taylor & Francis, UK.

Contents


3 Drop Log Flume
Complete ride cycle
pull up
drop
Acceleration (m/s/s)
Time (s)
30
20
10
0
-10
0
100
200
300
400
X
Y
Z
Orientation of boat


3 Drop Log Flume
3rd drop
Boat levels out at bottom of drop
Boat decelerating as it hits the water
Acceleration (m/s/s)
Time (s)
30
20
10
0
-10
333
335
337
339
341
343
X
Y
Z

Contents

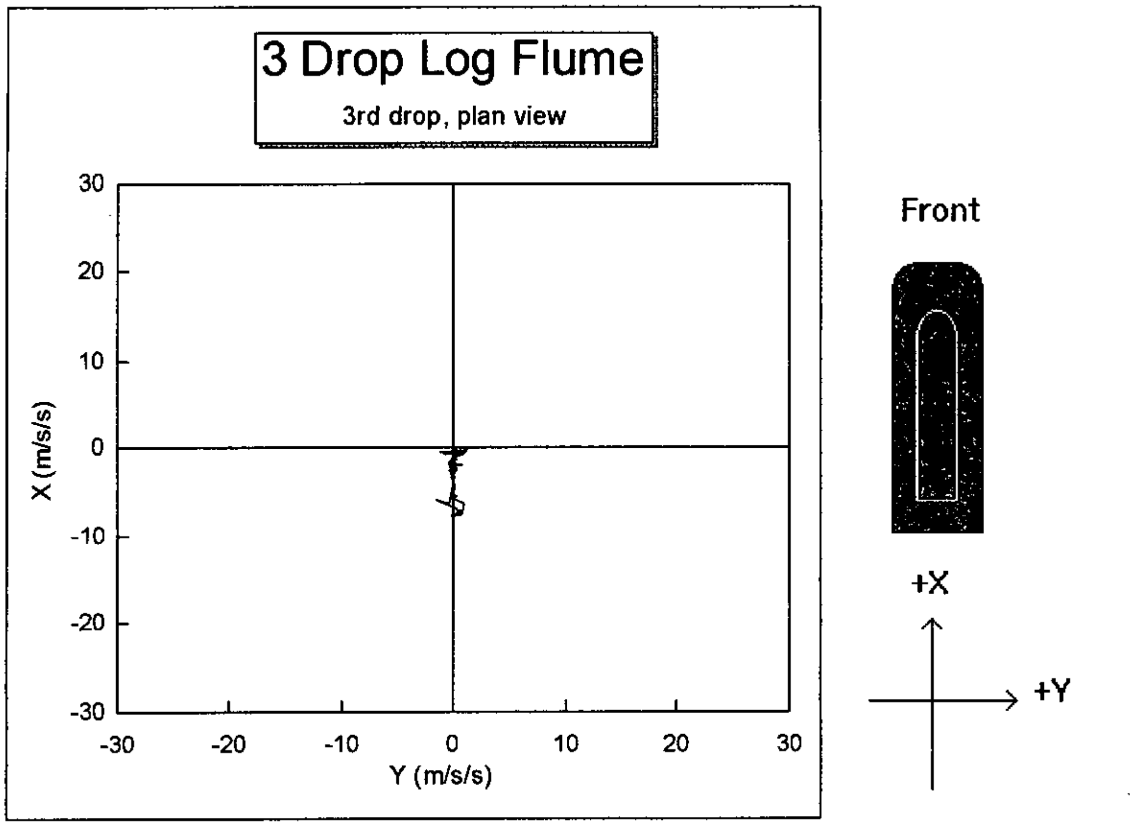


Figure B1.

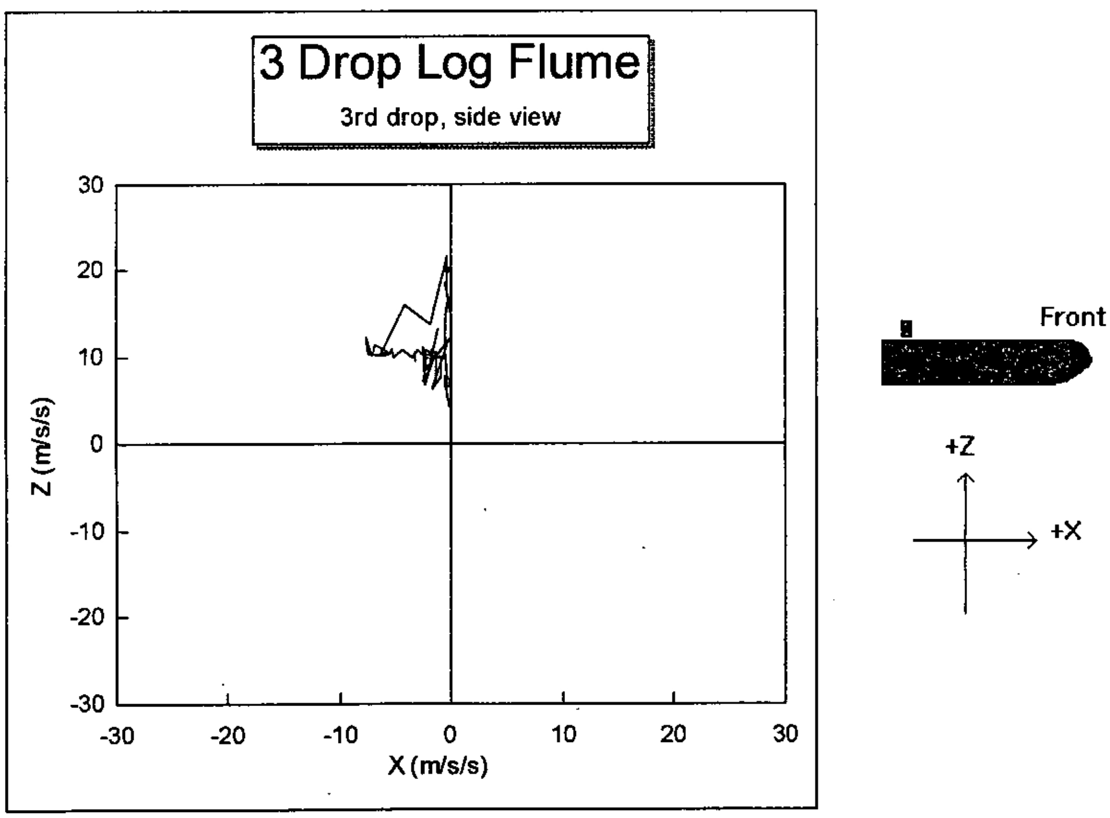


Figure B2.

Contents

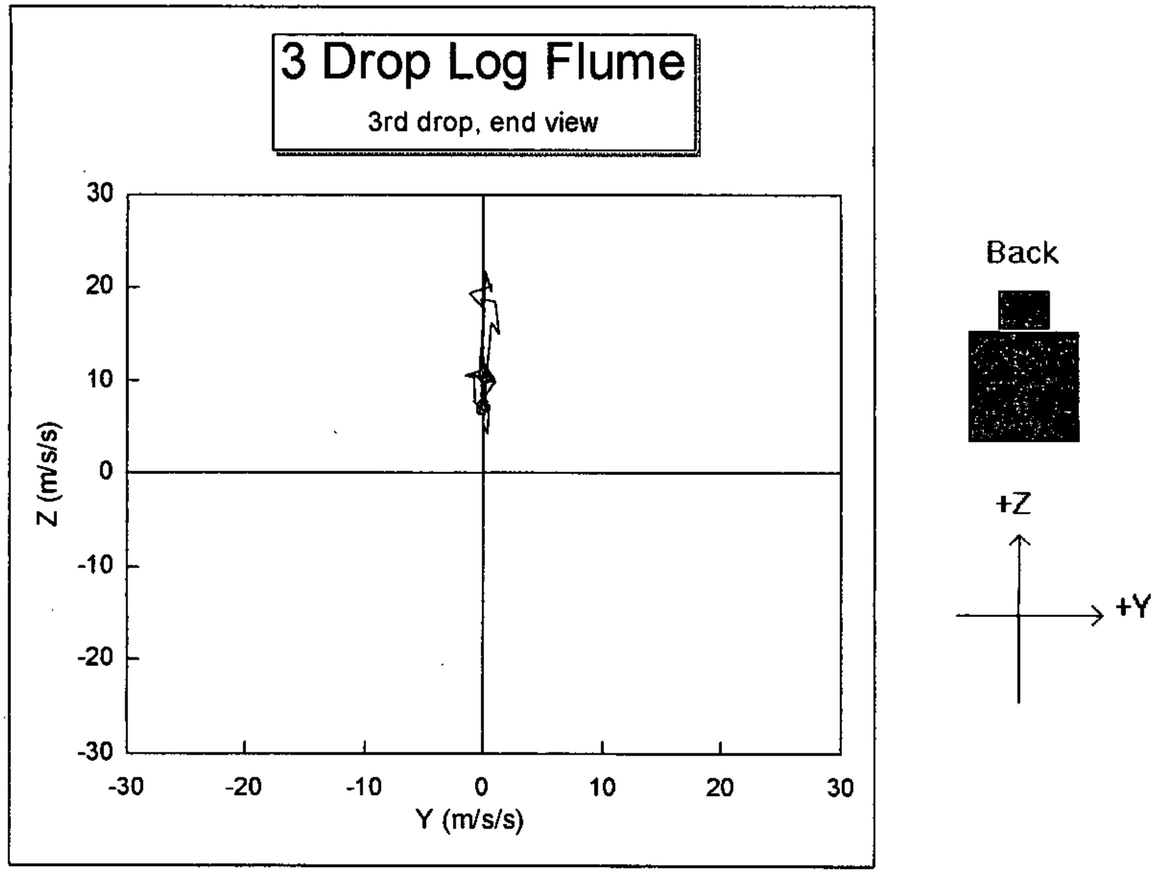


Figure B3.

Printed and published by the Health and Safety Executive
C3 2/97

HSE BOOKS

MAIL ORDER
HSE priced and free publications are available from:
HSE Books
PO Box 1999
Sudbury
Suffolk CO10 6FS
Tel: 01787 881165
Fax: 01787 313995

RETAIL
HSE priced publications are available from good booksellers.

HEALTH AND SAFETY ENQUIRIES
HSE InfoLine
Tel: 0541 545500
or write to:
HSE Information Centre
Broad Lane
Sheffield S3 7HQ

CRR 132

£15.00 net

ISBN 0-7176-1345-3

9 780717 613458

Contents