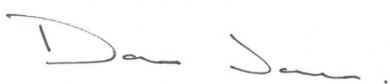


RUGBY BALL TRAJECTORY ANALYSIS FOR ALDI / NORTH MANCHESTER RUGBY CLUB

CLIENT	Aldi
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REPORTED BY		Professor David James Managing Director

PROJECT OVERVIEW	A retail development is planned for land near North Manchester Rugby Club. The planned development will be proximal to an existing rugby pitch, and there is a risk that balls may leave the field of play and present risks to traffic, parked cars, and pedestrians Worst-case scenarios were identified for the rugby pitch and a sophisticated trajectory model was used to predict the flight path of rugby balls, based on representative kick scenarios. Analysis of the trajectories revealed the position of the balls as they intersect the site boundaries. This information was used to recommend the height of any required ball stop mitigation.
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SITE INFORMATION

The development is planned for land to the west of one of the rugby pitches. The figure below shows an overview of the site.

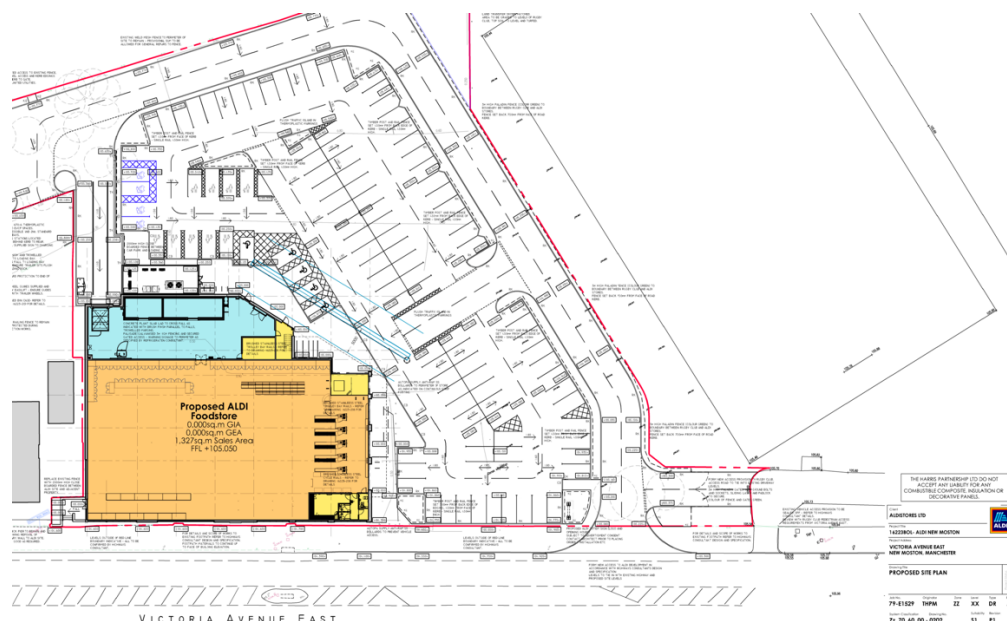


Figure 1. Overview of the planned development at Victoria Avenue East, near North Manchester Rugby Club (taken from the plans provided by Aldi).

The site overview shows an access road and parking for the retail development to the east of the rugby pitch. The developers have already indicated the location of a fence to demark the boundary. This report will provide a trajectory analysis to determine the recommended height of the fence.

An access road to the rugby clubhouse is located to the south of the pitch. As this access road already exists without ball stop mitigation, this potential area of risk will not be considered within this report.

TRAJECTORY MODEL

Labosport have developed a sophisticated trajectory model to analyse the trajectory of the rugby ball. The model was built in the numerical programming software 'Matlab' and incorporated aerodynamic drag and lift forces, and the significant complexities arising from the ball's rotation and its spheroid shape.

Under rotation, the rugby ball's cross-sectional frontal area constantly changes in relation to air flow. The angle of attack between the velocity of the ball and its pitch is also subject to continuous change as the ball rotates. Angle of attack, and cross-sectional area are both important determinants of the ball's aerodynamic coefficients and were accounted for in the model.

A SolidWorks model (size of Gilbert 'Match XV') was used to determine the frontal area by projecting the body onto planes from 0° to 90° relative to the longitudinal axes in interval steps of 10°. The results were imported to Matlab's curve-fitting-tool to create a continuous function to allow the calculation of frontal area at each time step through flight.

The model used published aerodynamic coefficients taken from wind tunnel studies on rugby balls at different angle of attack to the airflow (Seo et al. 2004, plus Djamovski et al. 2012).

The aerodynamic forces of drag (F_D) and lift (F_L) are proportional to the balls velocity relative to the air flow, frontal area, air density and the drag coefficient respectively lift coefficient. The forces are defined as:

$$F_D = \frac{1}{2} C_D \rho V^2 A$$

$$F_L = \frac{1}{2} C_L \rho V^2 A$$

with C_D and C_L are the non-dimensional drag and lift coefficients, ρ the air density in kg/m^3 , V the air stream velocity in m/s and A the frontal area of the ball in m^2 .

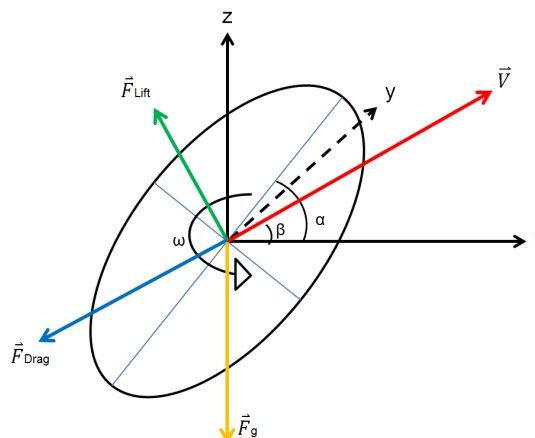


Figure 2. A free body diagram for the rugby ball trajectory model showing the aerodynamic drag and lift forces.

Due to the complexity of the flight dynamics, the trajectory can only be resolved by using a numerical time step approach whereby the ball conditions are calculated at small timesteps throughout the trajectory. The conditions at time step 1 are used to calculate the conditions at time step 2; the conditions at timestep 2 are used to calculate the conditions at time step 3 and henceforth. A timestep of 0.001 seconds was used to generate high-resolution trajectory data.

TRAJECTORY MODEL VALIDATION

The model was validated by comparing the computational output to an actual measured rugby ball trajectory. In his PhD thesis, Holmes (2008) created a kicking machine to investigate the flight distance and time of flight for different rugby balls in an indoor aircraft hanger (to avoid the influence of wind). Holmes also accurately measured the launch conditions from his kicking machine using high speed video.

The launch conditions measured by Holmes were used as inputs to the trajectory model and the predicted flight distance and time of flight were calculated. The model calculations were found to be very close to the measured trajectory and the model was deemed to be accurately validated.

Table 1. Validation of the trajectory model by comparison to measured flight data

	Holmes (2008) measured flight data	Trajectory model calculated flight data
Distance (m)	56.8	58.3
Time of flight (s)	3.70	3.74

KICK SCENARIOS

This report will consider various different reasonable worst case trajectory scenarios for the pitch. In the game of rugby, the ball can be kicked in various directions and with a range of velocities. Nonetheless, some trajectories are far more common than others. This trajectory assessment uses a proportionate approach by focusing on the common trajectories to determine the most likely scenarios where a ball may surpass the site boundary.

Labosport has significant experience and expertise in rugby and provides technical support to World Rugby, and the RFU. Labosport have drawn on their expertise to define trajectory scenarios where the ball may be kicked on a trajectory that surpasses the site boundary.

Kicking the ball into touch

Within the game of Rugby Union, a ball may surpass a boundary when a player 'kicks the ball into touch' to achieve an attacking line out. This event can happen in open play, or after a penalty. In either scenario, the ball is launched via a punt kick out of the hands.

A reasonable worst-case scenario has been identified as a player attempting to punt kick the ball into touch at a location of 5 metres inside the touch line, and at an angle of 45 degrees towards the opponent's goal. This scenario is a plausible game event and represents the maximum ball trajectory risk to the site boundary.

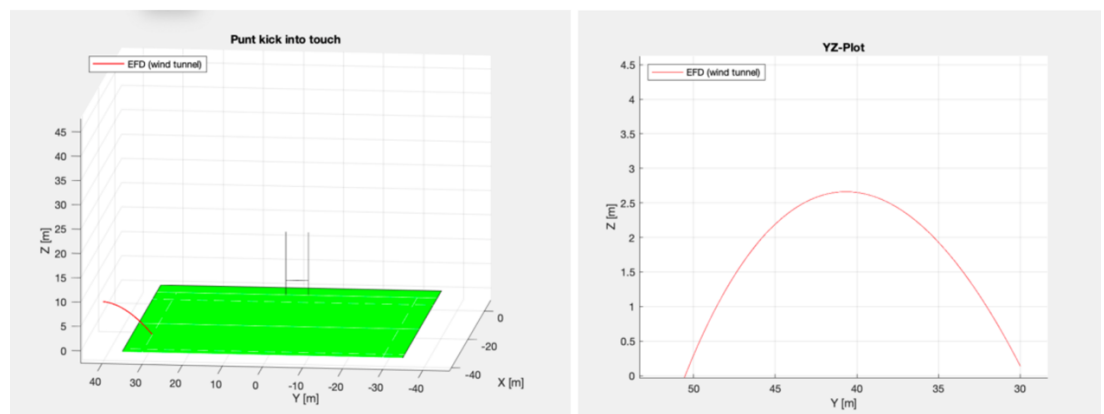


Figure 3. Trajectory visualisation for a punt kick into touch.

KICK VELOCITIES

Punt kick out of the hands

Pavely, Stuart et al (2010) analysed maximal punt kicks out of the hands from 10 professional rugby players. The mean measured distance of the kicks was 42 metres, and the mean launch angle was 18 degrees. A trajectory model can be used to calculate the launch velocity necessary to achieve such a distance. This study determined the punt kick launch velocity to be 28 m/s.

TRAJECTORY ANALYSIS

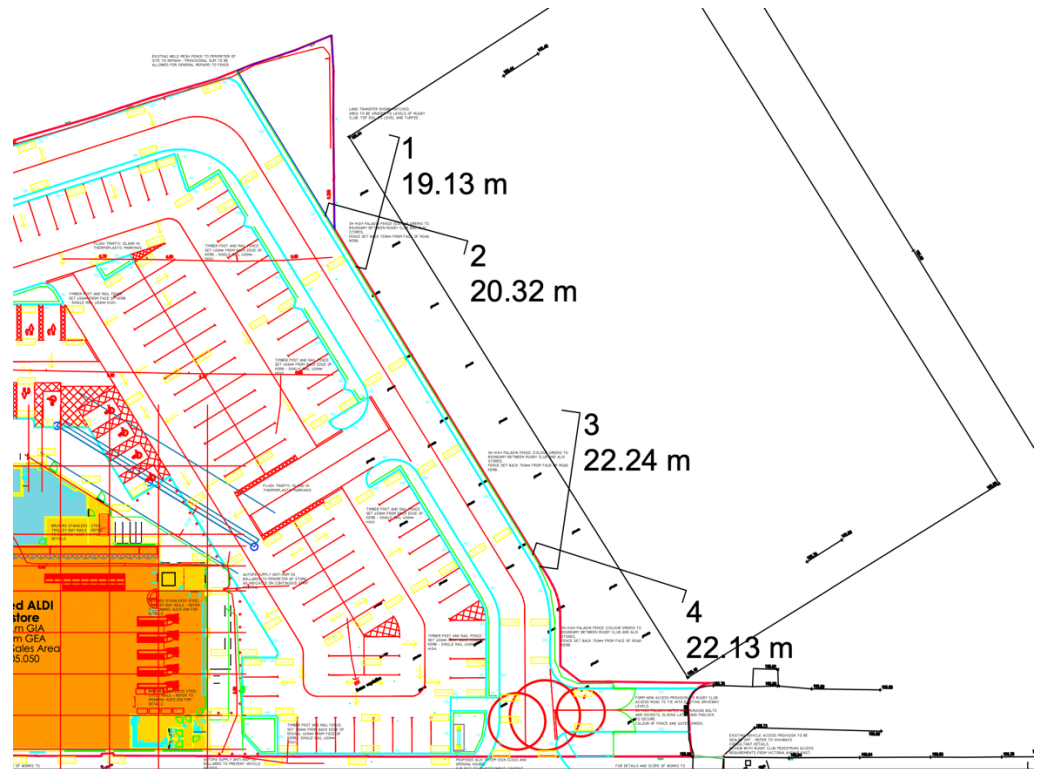


Figure 4. Overview of trajectory scenarios for the rugby pitch

Trajectory scenario 1 – punt kick into touch

This scenario relates to a punt kick into touch. The distance to the site boundary is 19.13 metres. **At this distance, the trajectory model predicts that the rugby ball will have a height of 2.4 metres when it surpasses the boundary.**

Trajectory scenario 2 – punt kick into touch

This scenario relates to a punt kick into touch. The distance to the site boundary is 20.32 metres. **At this distance, the trajectory model predicts that the rugby ball will have a height of 2.3 metres when it surpasses the boundary.**

Trajectory scenario 3 – punt kick into touch

This scenario relates to a punt kick into touch. The distance to the site boundary is 22.24 metres. **At this distance, the trajectory model predicts that the rugby ball will have a height of 2.1 metres when it surpasses the boundary.**

Trajectory scenario 4 – punt kick into touch

This scenario relates to a punt kick into touch. The distance to the site boundary is 22.13 metres. **At this distance, the trajectory model predicts that the rugby ball will have a height of 2.1 metres when it surpasses the boundary.**

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DISCUSSION AND CONCLUSIONS	This report has been prepared to assess the potential risk of balls surpassing the boundaries of a rugby pitch site proximal to new property development, and to advise on the type and level of mitigation recommended to provide a suitable level of protection. The exact frequency of events resulting in a rugby ball being kicked into adjacent area is unknown and impossible to predict with certainty (player skills, type of game and many other factors can influence this) hence a proportionate approach needs to be taken to provide safety to these users. In reality, there may be a “freak” kick that will result in a further than expected trajectory, but a balanced risk mitigation strategy needs to be implemented that is proportionate. Indeed, there are risks associated with many everyday activities, but plans need to be developed to reduce risk following good practical health and safety principles including a combination of likelihood and severity. In consideration of the risks posed by the simulated rugby ball trajectories in relation to the context of the location, this report recommends ball stop fencing to be erected in the location already identified on the site plan. We recommend that this ball stop fencing should have a minimum height of 3 metres. It is important to note that these recommendations may not stop all balls from landing beyond the site boundary, but it is predicted from the assessment of ball trajectory it will significantly reduce their frequency. This report does not specify the design of a mitigation system; however, many options are available for this recommended height. It is recommended the client discuss design options with the relevant stakeholders to ensure that whatever system if proposed is both suitable in mitigating the risk but also practicable for the football club’s day to day use.
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