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Effects of Crosswinds on Double Stacked Container Wagons

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Abstract

The side force due to crosswinds acting perpendicular to the lateral side of a railway carriage can cause the overturning of goods trains. It is particularly important for the double stacked container wagons. Thanks to containerisation of goods movement by the railways, the double stacked container wagons are frequently being used by various train operators around Australia and elsewhere. However, currently, no experimental data for crosswinds effects on the double stacked container wagons is available to assess the rollover risks. Therefore, the primary objectives of the study were to determine the steady crosswinds effects on the double staked container wagons under a range of crosswinds conditions. In order to address these objectives, several scale models were built and tested using six component force sensor in the RMIT Industrial Wind Tunnel. The airflow around the double stacked container wagons were visualised and documented using smoke and wool tufts. The results indicated that the side force and rolling moment coefficients increase with the increase of yaw angles. The highest side force coefficient was found in between 75 and 90 degree yaw angles.

Introduction

The lateral stability of goods train is an important safety issue as the lateral stability largely depends on aerodynamic forces caused by crosswinds, centrifugal force, and gravitational force due to curving and track cant. Aerodynamic forces are considered to have a significant influence on roll over problems, [2, 6, 8, and 11]. The critical wind velocity for overturning can be obtained from the static equilibrium of external forces acting on the carriage. For this reason, a detailed description of aerodynamic forces and moments and crosswind characteristics is required. Wind induced forces and moments especially the side force acting perpendicular to the lateral side of the carriage contributes most to the overturning of the carriage. Lift force also has some contributions to this process but due to the masses of typical rail vehicles is of a secondary concern. The aerodynamic characteristics of railway carriages under crosswinds largely depend on the external shapes of the carriage, track side embankments and bridges and tunnels.

FreightLink Australia operates double stacked container railway wagons on standard railway tracks around Australia. The maximum operating speed of the double stacked container carriages is approximately 115 km/h on tracks in Western and Southern Australia. However, the effects of crosswinds on these double-stacked container wagons are not well known as no experimental data for steady and unsteady wind conditions are available. Therefore, the primary objective of the study was to determine the steady crosswinds effects on high cube wagons in order to assess the rollover risks. In order to address these objectives, two scale models (1/15th scale) were built and tested in the RMIT Industrial Aeroacoustic Wind Tunnel under a range of wind speeds and yaw angles to simulate the crosswinds effects. The yaw angle can be defined as the angle between the railway carriage centreline and the mean direction of the wind as seen by the moving railway carriage (see Figure 7).

Experimental Facilities, Equipment and Models

The RMIT Industrial Wind Tunnel is a closed test section, closed return circuit wind tunnel and is located at the School of Aerospace, Mechanical and Manufacturing Engineering in Bundoora East Campus, Melbourne. The maximum speed of the tunnel is approximately 150 km/h. The rectangular test section dimension is 2 x 3 x 9 (metres) with a turntable to yaw suitably sized models. A remotely mounted fan drive motor minimises the background noise and temperature rise inside the test section. The free stream turbulence intensity is approximately 1.8%. A plan view of the tunnel is shown in Figure 1. The tunnel was calibrated before conducting the experiments. More details about the tunnel can be found in Alam [1].

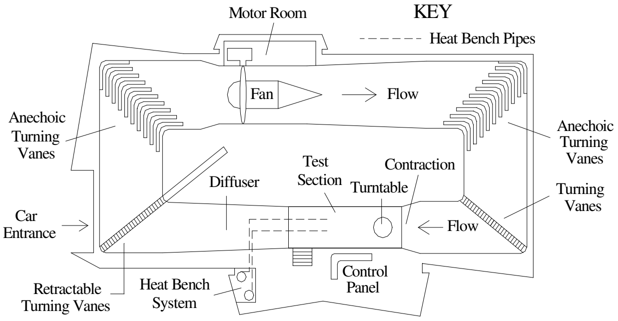

Figure 1: A Plan View of RMIT Industrial Wind Tunnel

Two 1/15th scale models: a double stacked container wagon SCT Logistics' configuration type and a double-stacked container wagon FreightLink type were used in this study. Both models are shown in Figures 2 & 3. The models were a close replica of the full-scale version, currently operated in Australia. However, the scale models are relatively smoother and have no corrugations compared to full scale. The models were made of plastics and timber. The external dimensions of SCT Logistics type and FreightLink model type were: L = 1075 mm, W = 165 mm & H = 180 (top containers of both models) and L = 810 mm, W = 165 mm & H = 105 mm (bottom container of SCT Logistics type) and L = 810 mm, W = 165 mm & H = 193 mm (bottom container of FreightLink container type). A special steel mounting bracket was made to attach these models to a six-component force sensor to measure simultaneously components of forces (drag, side force and lift force) and moments (rolling, pitching and yawing). The force sensor was connected to a PC located in the control panel via an A/D board. A purpose made commercial software was used to acquire the time averaged and time fluctuating data. The tunnel's reference speed was measured using a Pitot static tube located at the entry of the tunnel which was connected to a precision MKS Baratron pressure sensor via flexible tubes.

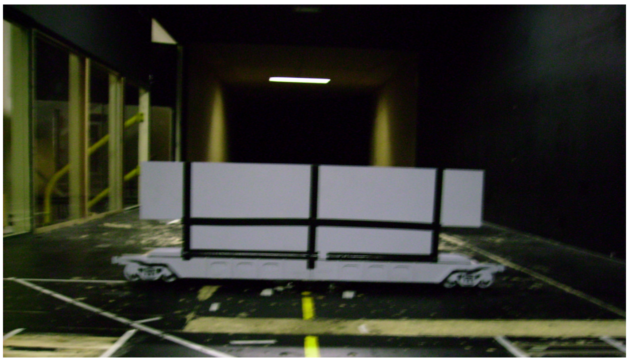

Figure 2: Double Stacked Container Wagon at RMIT Wind Tunnel (SCT Logistics Configuration Type)

Figure 2a: Double Stacked Container Wagon at RMIT Wind Tunnel (SCT Logistics Configuration Type) – a Close View

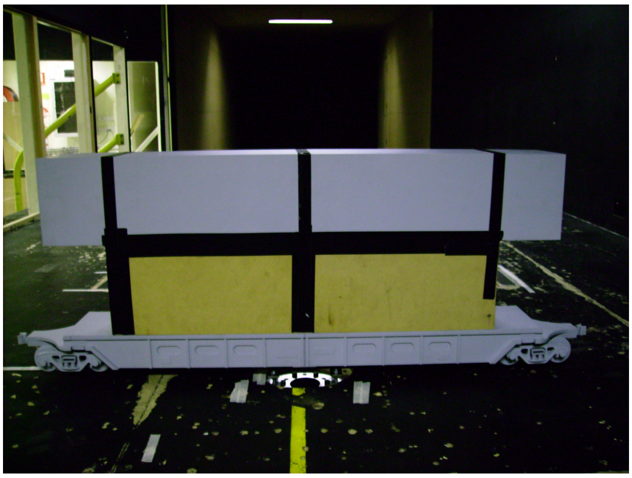

Figure 3: Double Stacked Container Wagon at RMIT Wind Tunnel at 90° Yaw Angle (FreightLink Configuration Type)

In this study, the effects of embankment, adjacent carriages and tunnel crossing were not considered.

Experimental Results and Discussions

Each model was tested as standard configuration in isolation (i.e., without the influence of other adjacent wagons and embankment). In order determine the effects of Reynolds number, both models was tested under a range of speeds (20 to 120 km/h with an increment of 10 km/h) and negligible effects were found at speeds over 40 km/h (see Figure 4). As the non-dimensional parameters are relatively independent of Reynolds number, therefore, the forces and moments non-dimensional parameters can be used for speed over 40 km/h. Each model was also tested under a range of crosswind yaw angles (0º to 90º with an increment of 10º). Both models were tested up to 120 km/h for zero yaw angles. Other yaw conditions were tested at 40 km/h due to strong side force and model's structural fragility. However, the results for higher speeds can be estimated as the non dimensional parameters are independent of Reynolds numbers.

The airflow characteristics were visualised using smoke at low speed (10 km/h) under a range of yaw angles (0, 45 and 90º yaw angles) for both models. The airflow was extremely turbulent and vortical in the leeward side at all yaw angles (0º, 45º and 90º). However, the 90º yaw angle has the significant effects on flow characteristics in the leeward side. The trail of the vortex extends at least 5 to 8 widths of the carriage in the down stream. It was also noted that a small upstream disturbance in the airflow generates fluctuating pressures on the carriage and cause the carriage to vibrate.

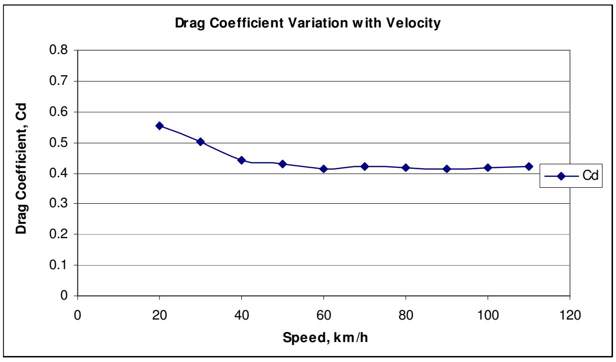

Figure 4: Effects of Reynolds Number

Effects of Crosswinds on Wagons in Isolation

The side force, lift force and rolling moment were converted to non-dimensional parameters of side force coefficient (C_S), lift force coefficient (C_L) and rolling moment coefficient (C_{RM}) using the following relationships:

$$C_S = \frac{F_S}{\frac{1}{2}\rho v^2 A}, \quad C_L = \frac{F_L}{\frac{1}{2}\rho v^2 A} \quad \text{and} \quad C_{RM} = \frac{M_R}{\frac{1}{2}\rho v^2 A h}$$

Where, F_S is the side force, F_L is the lift force, M_R is the rolling moment, ρ is the tunnel air density, v is the tunnel air speed, A is the side area of the carriage and h is the height of the carriage. In this study, the side area A was defined as the height of the carriage from the ground level (h) and the length of the carriage (L) ignoring the gap between the bogies (wheels).

The side force coefficient (Cs), lift force coefficient (Cl) and rolling moment coefficient (Crm) for both double stacked container wagons as a function of yaw angles are shown in Figures 5 and 6 respectively. As mentioned earlier, the data was obtained for the yaw angles from 0 to 90 degree and shown in right hand side of the graph. The left side of the graph is a mirror image. The side force coefficient increases with the increase of yaw angles for both models up to 75 degrees and thereafter remains almost constant. The highest side force coefficient is noted between 70 and 90 degree yaw angles. The double-stacked container wagon SCT Logistics type has relatively higher side force coefficient between 70 to 90 degree yaw angles compared to FreightLink type model. This variation is believed to be due to its extra height (increased side area) compared to the height of SCT Logistics bottom container.

The lift force coefficient increases with the increase of yaw angles up to 30° and thereafter reduces. Both models demonstrated similar trends.

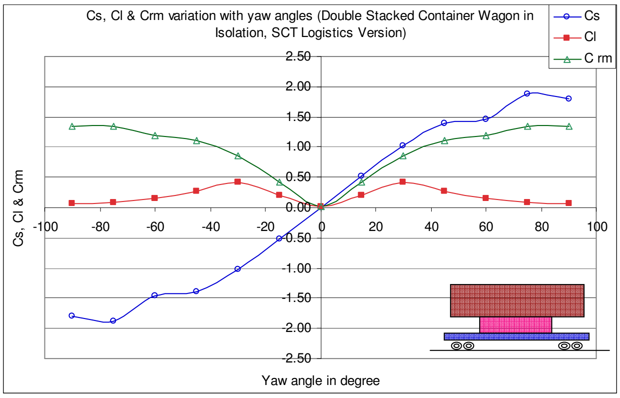

Figure 5: Side Force Coefficient as a Function of Yaw Angles (Double Stacked Container Wagons, SCT Logistics Version)

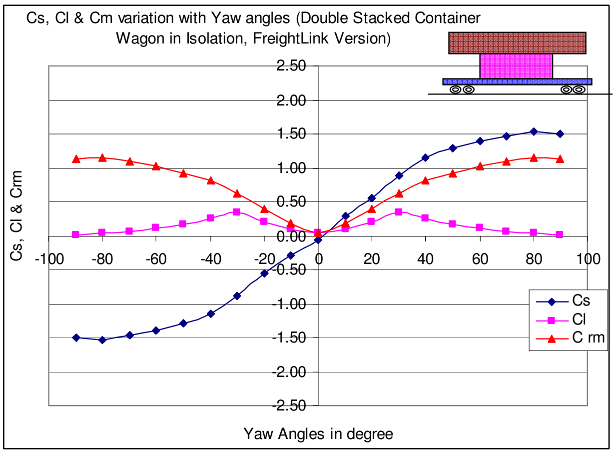

Figure 6: Side Force Coefficient as a Function of Yaw Angles (Double Stacked Container Wagons, FreightLink Type)

The rolling moment coefficient increases with an increase of yaw angles (from 0° to 75° yaw angles) for the SCT Logistics' and FreightLink types models and have very similar trends. However, the magnitude of the rolling moment coefficient is relatively small compared to SCT Logistics' type model. The rolling moment coefficients remain approximately constant between 75° and 90° yaw angles (see Figures 5 and 6).

The atmospheric wind generally varies in direction and speed continuously, as characterised by spectral analysis on long term wind records, [4, 9, and 11]. Generally, in the field, the wind velocity (V_W) can come from any direction relative to the mean direction of the carriage. The carriage speed (V_T) when combined with the wind velocity (V_W) generates a yaw angle (ψ) between the relative velocity (V_R) and the mean direction of the carriage. A vector diagram of velocity components for a moving vehicle in an atmospheric crosswind is shown in Figure 7. In the estimation of drag force, side force, lift force and their moments under atmospheric wind conditions, it is important to take the values of relative velocity (V_R) which can be defined as $V_R^2 = V_T^2 + V_W^2 - 2V_T\, V_W \cos(180 - \Phi)$. It can be noted that the wind angle (Φ) is the angle between the mean direction of carriage velocity (V_T) and the wind velocity (V_W) as shown in Figure 7.

Generally, in wind-tunnels, the airflow is smooth and statistically stationary and by yawing the carriage into the wind, the mean effects of steady state crosswinds is determined. In wind tunnel testing, the relative velocity equals the tunnel wind speed ($V_R = V_T$). In this study, it was found that the effects of Reynolds number on drag, side and lift force coefficients are negligible over 40 km/h speeds. Therefore, this non-dimensional parameter may be used for other speeds not tested here. It may be noted that the models were tested in a flat velocity profile (in this study). However, a real range of velocity profile can be experienced by a stationary or moving vehicles, for more details, refer to Cooper and Watkins [12]. The total aerodynamic force and disturbing moments due to crosswinds at the wheel base can be estimated based on the non-dimensional aerodynamic parameters found by the wind-tunnel testing for various container load configurations.

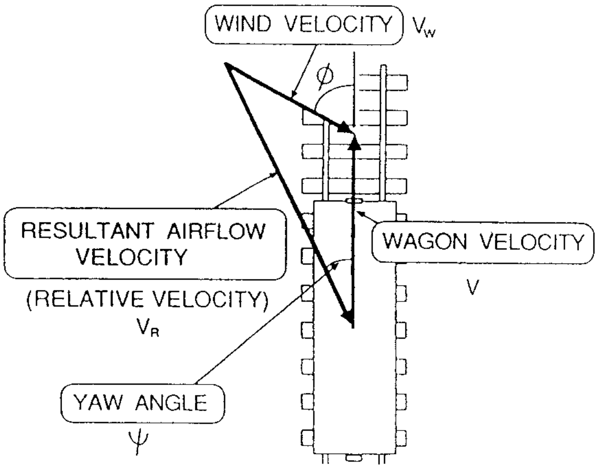

Figure 7: A Schematic of Local Wind Velocity, Wagon Velocity and Wagon Relative Velocity and their Angles (Saunders et al. [7])

The effects of gusts and transients were not included in this study. In order to understand the effects of gusts and transients on aerodynamic properties, wind statistical data is required. To the authors' knowledge, most meteorological and wind engineering data are available at heights greater than 10 m and for conditions of strong wind ($>10\, m/s$). As mentioned earlier, the atmospheric turbulence and mean wind characteristics vary as a function of distance from the ground and trackside obstacles and terrain types.

Effects of Yaw Angles on Rollover Moments under Various Loading Conditions

The wind speeds and wind angles have significant effects on relative velocity and wind yaw angles experienced by the train. The lateral component of the relative velocity plays the dominant role in roll over moments. For the given train speed, the yaw angle and relative velocity generally increase with the increase of wind speeds. The roll over moments for various container loading conditions due to steady aerodynamic forces can be estimated using the side force and rollover moment coefficients. Some preliminary estimates (not shown here) clearly indicates that the roll over can be possible at low wind speeds but under high wind angles (eg. 70, 80 and 90 degrees) depending on container loading conditions. Combination of high train and wind speeds under relatively high wind angles not only increases the risk of roll over but also generates significant lift force, and heaver container and train masses increase the restoration moments. However, the lift force generated by the high wind speeds reduces the restoration moment. The theoretical estimates in this study indicate that there is a possibility for the train to be rolled over with a cruising speed of 115 km/h at high wind yaw angles at relatively small wind speeds (less than 40 km/h). However, it is highly unlikely to be happened as the train has minimum possibility to face such a high wind yaw angles. Studies by various researchers [Cooper [4] for North America and Utz [10] for Germany] show that the vehicle with cruising speeds over 115 km/h hardly faces over 20 degree wind yaw angles. Although these studies were primarily conducted for road vehicles, the findings can be used for other surface vehicles including trains. It may be noted that these studies did not include the wind gust effects. However, some other studies (eg., Bearman and Mullarkey [3]) reported that "aerodynamic forces caused by wind gusts may be predicted safely by assuming the flow to behave in a quasi-steady way". Therefore, it is expected that the container wagon cruising at 115 km/h at 10 km/h wind speed will have minimum possibility to be rolled over as unlikely it will experience yaw angles over 20 degrees.

In this study, the models were tested in isolation which means the side forces in isolation may be less compared to the side forces of the wagons in a long train. Therefore, the results presented here could be under predicted. However, the drag forces will be over predicted compared to the drag forces of wagons in a long train.

Conclusions and Recommendations for Further Work

- The rolling moment coefficient increases with the increase of yaw angles. However, it remains almost unchanged after 75 degree.
- The magnitude of rolling moment coefficients for the double stacked container wagon (FreightLink configuration) has slightly lower values compared to the double stacked container wagon (SCT Logistics configuration). However, the coefficients for both configurations have demonstrated similar trends.
- The rollover estimate in this study can be used as guide only. In order to eliminate the rollover possibility it is highly recommended to apply some safety factor (depending on the duration of wind gusts and containers' masses) to the findings from this study.
- A real time risk of roll over moments analysis using an on board weather station (meteorological data) and wind tunnel experimental data can be extremely useful for the train drivers and operators.
- It is also recommended that a comprehensive study of track-side inputs and wind gustiness and atmospheric boundary layer effects on trains is important in order to accurately predict the rollover moments.
- The side force coefficients could be under predicted in this study as the models were tested in isolation. It is worthy to conduct further study to clarify this.

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