A Blow to Train Operations, Can strong winds cause derailment?

Tony Simes

Senior Transport Safety Investigator (Rail)

Australian Transport Safety Bureau

SUMMARY

In relation to train derailments, there have been times where the evidence has suggested a cause that would appear highly unlikely to the general observer. For example, if you told someone that the wind produced by a thunderstorm just blew a train off the track, they probably would not believe you. However, the Australian Transport Safety Bureau (ATSB) has investigated a number of freight train derailments where the evidence has indeed suggested this type of derailment scenario.

From an independent investigator's point of view, it is important for concepts that may appear unlikely, to be clearly explained, illustrated and supported by evidence. From a rail organisation's point of view, it is important to keep an open mind as to what factors could affect rail safety. Only then is it possible to encourage commitment from stakeholders to accept as possible, what they may have previously considered impossible.

This paper provides a brief summary of the ATSB investigation and discusses some of the theory behind thunderstorms, destructive winds and the effect of wind on rail vehicles.

INTRODUCTION

On 1 November 2006, a freight train derailed near Tarcoola, South Australia (there were no injuries).

Tarcoola is a small, remote town in central South Australia where the rail line from Darwin (in the north) joins the main east-west rail line crossing Australia (Figure 1). The freight train had been travelling from Darwin to Adelaide. As it approached Tarcoola from the north, the drivers noted a significant amount of lightning in nearby thunderstorms. While passing through Tarcoola, rain had started to fall. As its intensity increased, the rain was accompanied by strong winds and some hail.

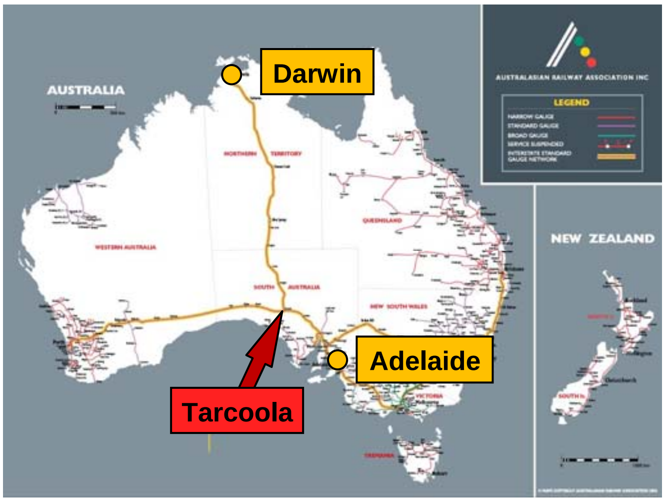


Figure 1: Location of Tarcoola, South Australia

While slowly accelerating along a straight section of track (heading in an easterly direction), the rain had become so heavy and the wind so strong that rain water was blowing under the sliding widows on the left-hand side of the locomotive cabin. While the drivers were attempting stop the water by placing towels in the left-hand side window channel, water suddenly began blowing in under the right-hand side window channel. The wind had rapidly changed direction and was now blowing water under the sliding widows on the right-hand side of the cabin.

At about the same time, while travelling at about 65 km/h, the driver felt a slight tug and/or surge through the locomotives. The driver also observed (via the locomotive gauges) a reduction of brake pipe pressure and an increase in brake pipe air flow. The train slowed to a stop and one of the drivers walked back to inspect the train. He discovered that only 16 of the 31 wagons were coupled behind the locomotives. Walking further back along the track, the driver found the remainder of the wagons, some of which had derailed and were lying on their side.

Investigators from the Australian Transport Safety Bureau (ATSB) arrived the following day and examined the site. The post derailment location of wagon components suggested that the 17th wagon was the most likely wagon to have derailed first. This wagon was the first in a series of low-floor 'Well Wagons' loaded with mostly empty, double stacked freight containers. The on-site evidence was unusual in that there was no evidence of a flange-climb derailment of wheels. The track structure was found to be in good condition, as was the rolling stock, and evidence suggested that the train had been handled in a manner consistent with normal driving practices. It appeared as though the wagons had simply tilted and rolled over onto their sides.

Wind induced lateral force, especially that acting on the side of a wagon, is considered to contribute significantly to body roll and potential wagon roll-over. In the absence of any evidence to the contrary, the ATSB closely examined the possibility that severe environmental conditions at the time of the derailment may have led to a wagon roll-over scenario.

Figure 2: Derailment site - Tarcoola, South Australia

Data was obtained from an automatic weather station located at the Tarcoola airfield, approximately four kilometres west of the derailment site. It was evident that a significant meteorological change occurred around the time of the derailment. Average wind speed almost doubled with a directional change over about 115 degrees. The temperature fell 5.5 degrees Celsius over a two minute period, and more than 10 mm of rain fell in five minutes. The maximum wind gust recorded at Tarcoola was 74 km/h at 9:19pm (four minutes before the derailment). The same weather system recorded 91 km/h wind gusts at Coober Pedy (185 km north) and 80 km/h wind gusts at Woomera (215 km east).

Thunderstorms

A thunderstorm is a generic term for a relatively small scale convective process where warm, humid air near the ground rises rapidly into an unstable atmosphere. Severe winds in thunderstorms originate as vertical 'downbursts' from high within the thunderstorm cloud structure. Thunderstorms can occur anywhere in Australia, whereas cyclones (hurricanes and typhoons), which are characterised by violent circular winds, generally only occur in the northern areas where the ocean temperatures are higher (>26 degrees Celsius).

In Australia, a severe thunderstorm is defined by the Bureau of Meteorology as one which produces:

- hail, diameter of 20 mm or more; or
- wind gusts of 90 km/h or greater; or
- flash floods; or
- tornadoes, or
- any combination of these.

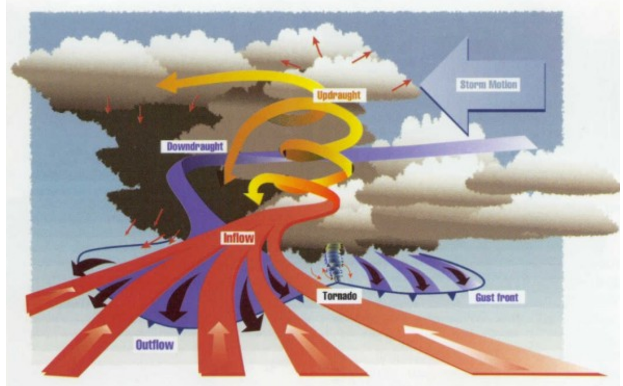


Figure 3: Thunderstorms

Downbursts develop after warm moist air rises into the atmosphere and pushes up under cold dense air. As the moisture condenses, hail is formed and circulates within the upper areas of the thunderstorm. When the weight of the circulating water and ice can no longer be supported by the updrafts, the water and ice begins to fall, dragging the surrounding air downwards. Nearby air is cooled by the downwards moving water and ice, further accelerating the downward rush of air. As the downburst reaches the ground, the air rapidly spreads out causing extreme winds at ground level that can be comparable to a weak tornado (Figure 4). While a thunderstorm, by definition, produces wind gusts of at least 90 kilometres per hour, peak winds can exceed 160 kilometres per hour.

Downbursts can be described as either a ‘Microburst’ (diameter of 4 km or less) or ‘Macroburst’ (diameter greater than 4 km).

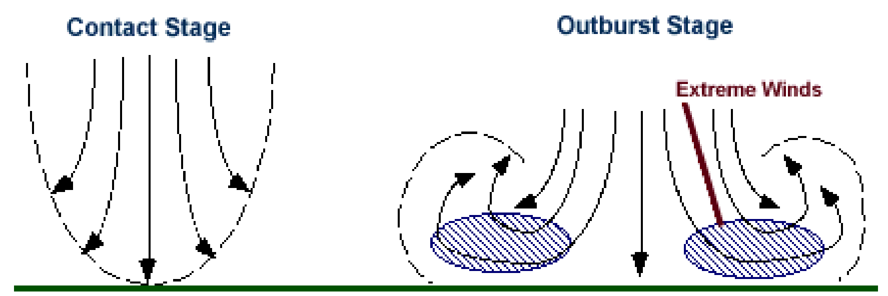


Figure 4: Downbursts

Wind effects on a rail vehicle

Wind is an external factor that can apply a force on rail vehicles. Some wagons, such as box wagons or double stacked container wagons can have large side areas which act like a sail when considering wind induced lateral forces acting on a wagon. As the combined side area of a wagon increases, so too will the resultant wind force acting on the wagon.

Turning moment is a function of force acting at a distance from a pivot point. When wind acts on the side of a rail wagon, the force exerted by the wind induces an overturning moment on the wagon. This is opposed by a restraining moment due to the weight of the wagon.

$Fs = Side\ Force$

$Hs = Centre\ of\ Side\ Area$

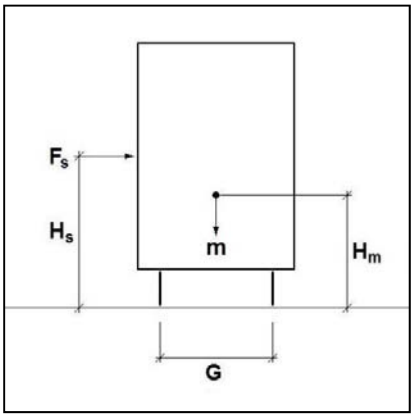
$m = Vehicle\ Mass$

$Hm = Centre\ of\ Mass$

$G = Track\ Gauge$

$Ms = Overturning\ Moment\ due\ to\ Side\ Force$

$Mv = Restraining\ Moment\ due\ to\ Vehicle\ Mass$



Assuming the wind acts evenly across the side of the wagon, the side force may be taken as acting at the vehicle’s centre of side area. Therefore, overturning moment is calculated by;

$$Ms = Fs\ Hs \quad (1)$$

Gravity acting on the vehicle mass provides the down-force that restrains a vehicle from overturning. The down force is taken as acting vertically from vehicle’s centre of mass. Assuming that the vehicle mass is evenly distributed across each axle and the vehicle remains vertical; the centre of mass is calculated as half the track gauge. Therefore, restraining moment is calculated by;

$$Mv = 9.81\ m\ G/2 \quad (2)$$

As wind force increases, the weight of the vehicle can no longer restrain the overturning moment and a wheel will lift off the rail. 100% wheel unloading will occur when overturning moment and restraining moment are equal. The percentage of wheel unloading can be calculated using the ratio of the overturning moment (formulae 1) and the restraining moment (formulae 2).

$$\%\ Wheel\ unloading = \frac{Ms}{Mv} * 100 \quad (3)$$

Generally, all elements of the above equations are known, except for the side force due to wind.

Wind force

When wind acts on an object, it applies a force in the direction that the wind is acting on that object. Side force due to wind can be calculated using the following formula:

$$Fs = \frac{1}{2}\,\rho\,V^2\,Cs\,A \qquad (4)$$

Where:

$Fs = Side\ Force$

$\rho = Density\ of\ Air\ (1.25\ kg/m^3)$

$V = Wind\ velocity\ (m/sec)$

$Cs = Side\ Force\ Coefficient$

$A = Side\ Area\ (m^2)$

Calculation of percentage wheel unloading is achieved by substituting the formulae for side force (4), overturning moment (1) and restraining moment (2) into the formula for wheel unloading (3).

$$\%\ Wheel\ unloading = \frac{\rho\,V^2\,Cs\,A\,Hs}{9.81\,m\,G} * 100 \qquad (5)$$

It should be noted that this is a simplified method that assumes the vehicle remains vertical and the wagon's combined centre of mass acts continuously at the centre point between the two rails (ie. there is continuous wheel/rail contact and no allowance for body roll). In addition, a critical element of wind force on a moving train is the combined effects of atmospheric wind (due to weather) and induced wind (due to train movement). Atmospheric wind is simply the speed and direction of wind relative to a stationary object. Wind speed due to train movement is equal to train speed, but acts in a direction opposing the direction of train movement. The effective wind (speed and direction) is the combined effects of atmospheric and induced wind. The effective wind speed may be significantly higher in magnitude, but will act at an angle less than 90 degrees to the wagon if it is moving. So long as train speed is known, along with wind speed and angle relative to the train direction, effective wind (speed and angle) can be calculated using basic trigonometry.

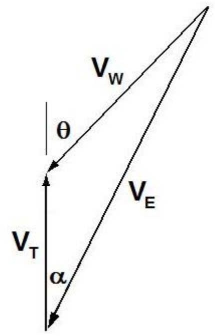
$V_E = Effective\ wind\ speed$

$\alpha = Effective\ wind\ angle$

$V_T = Train\ speed$

$V_W = Wind\ speed$

$\theta = Wind\ angle$



All elements of this formula are now known, or can be specified, except for the coefficient used to calculate side force (Cs), which is derived from wind tunnel testing. Wind tunnel testing examines the aerodynamic properties of railway wagons by using scale models to measure the relationship between wind angles and the coefficient used to calculate wind force. A typical output is illustrated in Figure 5. Based on the wind tunnel test results for side force coefficient the percentage wheel unloading can now be calculated for different wind speeds, wind angles and vehicle speed combinations.

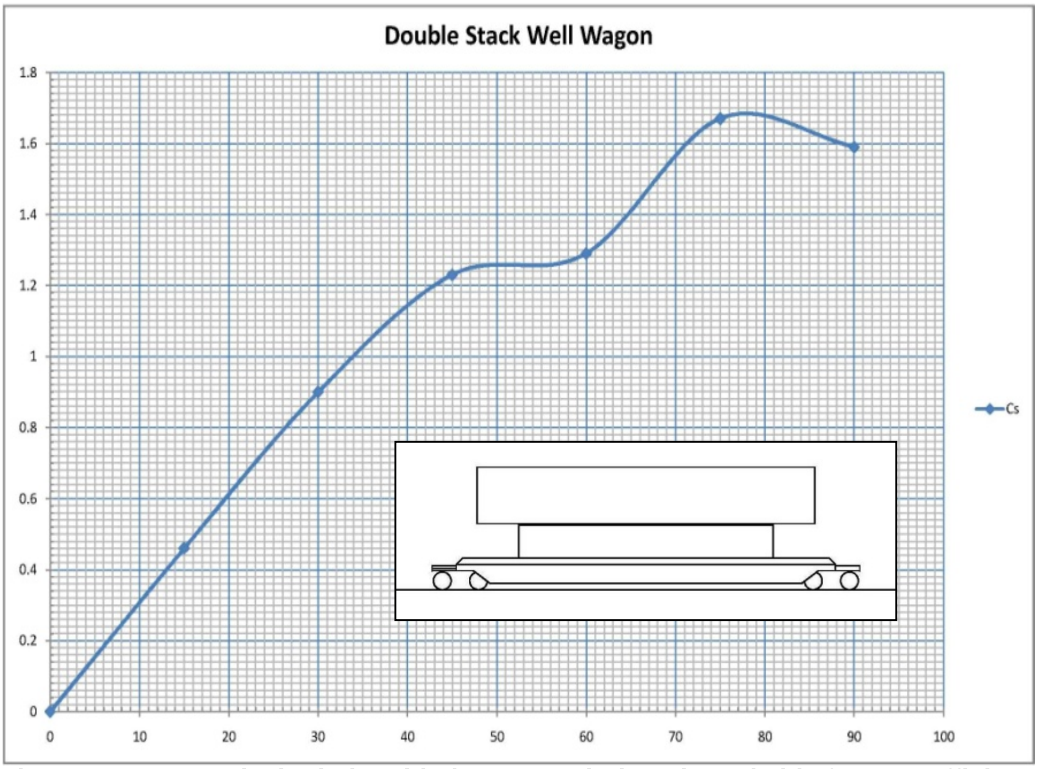


Figure 5: Typical relationship between wind angle and side force coefficient

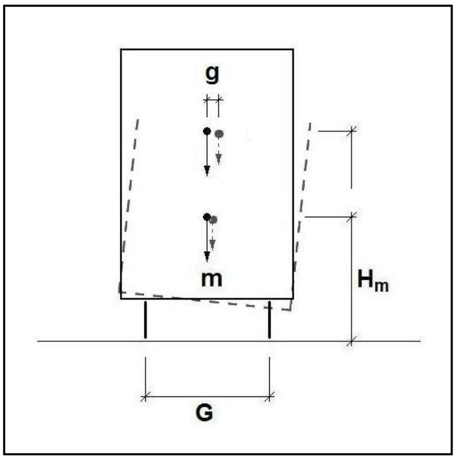
However, as mentioned above, the calculation assumes that the wagon's centre of mass acts at the centre point between the two rails. In reality, a rail wagon (bogies, wagon body and load) is not a rigid structure. Bogie suspension and a wagon's natural oscillation and/or an external force such as wind loading will allow a wagon body to roll slightly from side to side. The consequence of this movement is that the wagon's combined centre of mass will also shift from side to side. The magnitude of this shift for the same roll angle will increase as the height of the centre of mass increases above rail level.

$m = Vehicle\ Mass$

$Hm = Centre\ of\ Mass$

$G = Track\ Gauge$

$g = lateral\ change\ in\ centre\ of\ mass$



Since the centre of mass has shifted, the restraining moment will decrease as the distance from the pivot point decreases. Therefore, the formula for percentage wheel unloading becomes:

$$\%\ Wheel\ unloading = \frac{0.5\ \rho\ V^2\ Cs\ A\ Hs}{9.81\ m\ (\ 0.5\ G - g)} * 100 \qquad (6)$$

The calculation of lateral change in centre of mass is dependent on its height above track and the angle of tilt, and can be calculated using basic trigonometry.

Calculations applied to the wagon configuration at Tarcoola

The wagons were loaded with double-stacked freight containers, providing a large side area for the wind to apply an overturning force. Conversely, the containers were mostly empty, thereby providing minimum force restraining the tendency to overturn. Based on the wind tunnel test results for side force coefficient, the percentage wheel unloading was calculated for different wind speed and vehicle speed combinations. The calculations suggested that 100% wheel unloading could occur when atmospheric wind speed was about 100 km/h at an angle between 60 degrees and 70 degrees to the direction of train travel. However, the required wind speed to cause 100% wheel unloading could be significantly less if wagon tilt is taken into consideration.

The Australian Bureau of Meteorology weather station at Tarcoola airfield (approximately four kilometres west of the derailment site) recorded a maximum wind gust of 74 km/h at around the time of the derailment. A characteristic of a downburst is that they can exhibit very high wind speeds while only affecting areas up to 1 km wide. For example, the same weather system recorded wind gusts in excess of 90 km/h at Coober Pedy (185 km north). Consequently, it is possible that a downburst (or microburst) of cold air in the vicinity of the derailment site could create wind speeds significantly higher than those recorded at Tarcoola.

The investigation concluded that, in the absence of any evidence to the contrary, it was possible that the combined effects of wind load (due to the prevailing thunderstorm conditions) and the wagons' natural oscillations while travelling, could have been sufficient to initiate the overturning of the lightly loaded, double stacked freight wagon.

Similar derailment

On 11 November 2008, a freight train derailed near Loongana, Western Australia (there were no injuries). Similar to the derailment at Tarcoola, the train was loaded with double-stacked freight containers, though in this case they were loaded on a flat wagon. Again, the containers were mostly empty.

The freight train had been travelling from Perth to Melbourne. As it travelled on a long straight section of track near Loongana, the drivers observed pockets of lightning and wind induced dust moving towards them from a north to north-easterly direction. The train had been travelling at about 105 km/h, but the wind caused the train speed to rapidly reduce. The driver estimated that the train lost about 35 km/h over a distance of about 3.5 km, despite the throttle being set at eight notches (full power).

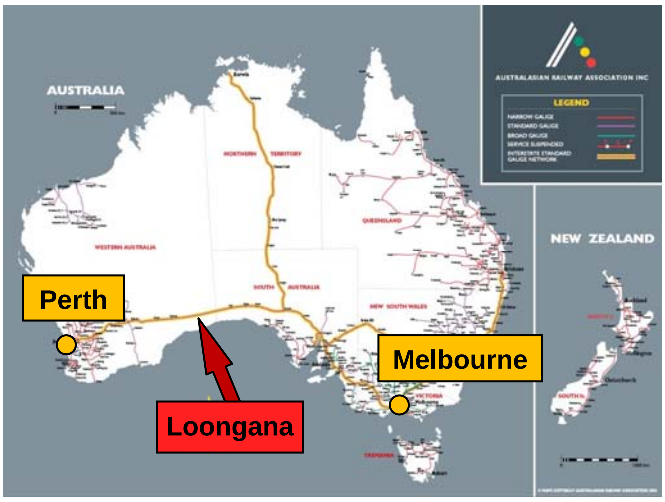


Figure 6: Location of Loongana, Western Australia

Similar to the Tarcoola incident, the site evidence was not consistent with what would normally be expected at a derailment site. It too appeared as though the wagons had simply tilted and rolled over onto their side.

Recorded weather observations were not available in the near vicinity of Loongana. However, data recorded at a location 113 km ahead of the train indicated wind gusts of about 75 km/h associated with the same thunderstorm activity. This was confirmed by a track inspector who had been travelling on the track ahead of the train on the day of the derailment. He reported that strong gusts of wind had shaken his road/rail vehicle and he considered the conditions to be some of the most extreme he had experienced during his career.

Based on the wind tunnel test results for side force coefficient, the percentage wheel unloading was calculated for different wind


Figure 7: Derailment site – Loongana, Western Australia

speed and vehicle speed combinations. The calculations suggested that 100% wheel unloading could occur when atmospheric wind speed was about 80 km/h at an angle between 60 degrees and 80 degrees to the direction of train travel. However, the required wind speed to cause 100% wheel unloading could be significantly less if wagon tilt is taken into consideration.

In this case, the closest Bureau of Meteorology weather station was at Forrest (approximately 113 kilometres east of the derailment site). This weather station recorded wind gusts in excess of 70 km/h for the same weather system. Considering the characteristics of thunderstorms and associated downbursts, it possible that wind gusts in the vicinity of the derailment site could create wind speeds significantly higher than those recorded.

The investigation concluded that the combined effects of atmospheric wind, induced wind due to train movement and wagon body roll were most likely sufficient to initiate the overturning of the lightly loaded double stacked wagon.

CONCLUSION

The derailment at Tarcoola (South Australia) on 1 November 2006 is an example where the evidence suggested a derailment scenario that initially appeared highly unlikely. However, following close examination of the evidence and calculations based on wind tunnel testing, it became evident that strong winds were sufficient to initiate the overturning of the lightly loaded double stacked wagon.

In Australia, people generally associate destructive winds with the cyclonic storms that only occur in the northern areas of the country. However, history shows that destructive winds in the form of downbursts can also be associated with thunderstorms and these can occur anywhere in Australia.

Initially, the concept of train derailment due to strong winds created by thunderstorms in the southern areas of Australia was met with a level of scepticism. However, in this case, the train operator remained open to the concept of wind induced roll-over and implemented strategies aimed at reducing their risk. The operator implemented procedures to ensure that the combined centre of mass of double stacked wagons was as low as possible. Where containers were to be double stacked, the gross mass of the top tier container(s) was to be equal to or less than the gross mass of the bottom tier container(s).

About 2 years later (11 November 2008), a freight train operated by a different organisation derailed at Loongana, Western Australia. Similar to the Tarcoola incident, the investigation found that strong winds contributed to the derailment. Again, the train operator remained open to the concept of wind induced roll-over and implemented strategies aimed at reducing their risk.

It is recognised that double stacking containers for rail transportation is common practice in Australia and is considered to be an essential practice by rail operators, from an economic point of view. It is also recognised that the environmental conditions that may increase the risk of wind induced derailments are very unpredictable and history has shown that the incidence of these derailments is very low. Importantly, it would appear that rail operators have accepted that strong winds can present a risk to their operations and they continue to implement strategies aimed at managing that risk.