Simulation of Heavy Trucks in Inclement Weather

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Abstract

1.0 Introduction

It is postulated that high sided vehicles (such as trucks) are inherently unstable under inclement weather conditions, most notably gusting winds, empty trailers and icy roads. Intuitively, this statement is accepted by accident researchers. However, this study utilized computer simulation to assess the degree of vehicle instability and provide information as to what the safe speed should be under various combinations of weather, road and vehicle conditions. To do so, a dynamic simulation was done on an Excel spreadsheet with the changing trailer angle calculated using Runge-Kutta numerical methods.

Approach

Essentially, the angle the trailer moves (a.k.a. yaw angle) is a good indicator of the stability of the truck and whether an accident could occur or not. For instance, it is speculated that if the trailer angle exceeds 5° then the truck becomes extremely unstable and an accident is most likely to occur. Therefore, the whole idea behind the simulation program is to calculate the yaw angle.

To calculate the yaw angle $\chi$ shown in Figure 1, four moments first needed to be determined. A moment causes rotation of an object about a point and is equal to a force acting upon an object multiplied by the perpendicular distance to the point of rotation. With a heavy truck, these four moments combined cause a rotation of the trailer about the kingpin, hence rotating the trailer and creating a yaw angle.

Figure 1 shows the four moments applied upon the trailer. The first moment, M\textsubscript{1}, is due to the forward velocity of the heavy truck. The second moment is due to the wind forces acting upon the trailer (M\textsubscript{2}). The third moment is due to the lateral tire friction forces of the trailer (M\textsubscript{3}). M\textsubscript{3} depends greatly upon the road surface condition. For example, if the surface is slick ice, M\textsubscript{3} would be much less than if the road surface was dry. Finally, the fourth moment (M\textsubscript{4}) applied to the trailer is the vortex shedding of the air behind the trailer (a.k.a. wind turbulence at the rear of the trailer).

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After determining the moments, the spreadsheet program could be set up. Fourth Order Runge-Kutta numerical methods were used to calculate the angle of the trailer changing with time.

Wind Gust Effects

The program was set up to best simulate a real-life situation where the heavy truck experiences a specified wind gust range, with the wind speeds varying randomly with time within this gust range.

Analyzing a heavy truck under fluctuating winds will produce much higher yaw angles than a steady wind. This can be explained by thinking of sailing. When a steady wind is applied, the boat tips to a certain angle and then does not move. However, if the wind is gusting, the boat rocks and can rock to a point of tipping over.

This same analogy occurs with the trailer of the heavy truck. When a wind gusts and then presides, the trailer moves from one side to the other, except it rotates around the kingpin instead of rocking back and forth like the boat. However, if the wind gust is applied just when the trailer is about to switch directions, this amplifies the amount the trailer will move. If this occurs more than once in a row, the yaw angle can increase to unstable conditions. This is analogous to that of pushing a friend on a swing to get them to go higher. If you keep on pushing them just when they are switching directions, you can push them higher and higher without having to apply more force each time. This occurrence, called resonance, can happen on the road where the yawing of the trailer can bring the truck out of control and lead to an accident.

Analysis
A 48 foot (14.63 m) trailer was analyzed in empty and full loading conditions, along with different wind speeds, and five different types of road surface conditions (from slick ice to dry). This gives 250 different combinations (Figure 2).

The wind gust range chosen for this analysis was 20 kph. The reason this was chosen is because it is a commonly occurring wind gust range for weather in Manitoba as indicated from Environment Canada weather data on the television. Also, higher wind speeds for full loading conditions were analyzed compared to empty conditions in order to try and see when the truck becomes unstable. A full truck has more frictional force to keep it from sliding on the road surface versus an empty truck.

Fundamentally, the largest angle the trailer moves over a time period is a good indicator of its stability in a particular situation. Also, the longer the time period the yaw angle is calculated, the more accurate the results will be. Each simulation run of the program is 20 seconds. Therefore, to increase the time period considered for each combination, the program was run 100 times for each combination, giving a time period evaluation of 2000 seconds or 33 minutes, 20 seconds. The largest angle that occurred in this time frame was recorded and used to come up with the final results.

**Results**

The yaw angle data collected from the simulation runs proved to be quite useful, especially in demonstrating resonance of the trailer mentioned earlier.

The graphs in Figures 3 and 4 show the yaw angle of the trailer varying over time as calculated by the simulation program at wind speeds from 30-50 kph with an empty trailer on slick ice. Comparing the graphs, both occur under the same conditions, but the difference between the two is one shows the trailer experiencing resonance (Figure 3) and the other shows the yaw angle changing with time with no resonance (Figure 4).

The two ellipses on the graph in Figure 3 show instances where resonance occurs. In these instances, the wind gusts are being applied just when the trailer is switching directions. The graph below in Figure 4 shows the yaw angle changing with time under the same conditions as Figure 3. Except this time, no resonance occurs and as a result much lower yaw angles are achieved. In both situations, the size of the wind gusts may be equal, but it is when the gust is applied that makes the difference. If the wind gust is applied just when the trailer is switching directions, this amplifies the effects of the gusts and can result in resonance. This shows that the wind can gust in such a way causing resonance, which causes the trailer to yaw more and increases the likelihood of an accident.
Figure 3: Resonance of the trailer yaw angle resulting from pulsating wind gusts

Figure 4: Resulting yaw angle with time with no resonance

Therefore, wind gusts and resonance play a major role in limiting the maximum wind speeds a heavy truck can safely drive through. As the wind speeds increase, the more likely the effects of resonance will cause the yaw angle to exceed the safety maximum (5 degrees).

Using this value, the table below in Figure 5 shows the maximum wind speeds a 48 foot trailer under various conditions could drive at. Remember, these maximum speeds were determined because resonance occurred in the time frame the simulation was run. Chances are, if the simulation was run for a longer time, these numbers would be lower.

<table>
<thead>
<tr>
<th>load condition</th>
<th>shear ice</th>
<th>ice</th>
<th>snow</th>
<th>wet</th>
<th>dry</th>
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</thead>
<tbody>
<tr>
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<td>20-40</td>
<td>40-60</td>
<td>&gt; 50-70</td>
<td>&gt; 50-70</td>
<td>&gt; 50-70</td>
</tr>
<tr>
<td>full</td>
<td>40-60</td>
<td>60-80</td>
<td>&gt; 100-120</td>
<td>&gt; 100-120</td>
<td>&gt; 100-120</td>
</tr>
</tbody>
</table>

Figure 5: Maximum wind speeds (kph) a heavy truck can handle safely with a 48 foot trailer under certain loading and road surface conditions

The results also showed that increasing the load capacity reduces the movement of the trailer. Figure 6 depicts a graph comparing the maximum yaw angle that occurs with empty and fully loaded trailers at various wind speeds on ice. As can be seen, the yaw angle of an empty trailer increases considerably more with increased wind speed than a loaded trailer put under the same conditions. Similar results occurred for the other vehicle speeds and road surface
conditions analyzed. The reason this occurs is the adding weight to the trailer increases the friction between the tires and the road surface, hence decreasing the amount the trailer moves in the wind.

![Wind Speed vs. Yaw Angle](image)

**Figure 6: Load Comparison of a heavy truck travelling 100 kph on ice**

This is important to know because it shows that empty trailers under windy conditions are more susceptible to accidents due to inclement weather than loaded trailers.

Another factor the results showed that are related to friction is the road surface condition.

![Road Surface Condition vs. Yaw Angle](image)

**Figure 7: Yaw Angle Changing With Road Surface Condition**

Figure 7 above shows the yaw angle decreasing from increased friction from road surface condition (empty trailer, 40-60 kph wind, 100kph truck speed). Similar results occurred with all the other conditions analyzed. Hence, a conclusion can be made that the stability of the truck decreases when the road surface condition goes in the following order of road surface condition: dry, wet, snow, ice, to slick ice.
**Summary**

*I know this is weak*

Analysis of a heavy truck under various wind speeds, road surface and loading conditions using a simulation programs demonstrated how resonance of wind gusts plays a large role in determining the maximum wind speed a heavy truck can safely drive in. It was also shown that the maximum wind speeds a truck can handle increases with increased friction between the tires and the road, caused by increased loading, and/or road surface type.

However, there are limitations to this analysis and the largest one is human factor. For instance, visibility was not taken into account. It would like to be mentioned that inclement weather conditions combined with poor visibility can worsen the effects. When the driver can not see the road, it is more difficult to correct for trailer yaw hence increasing the likelihood for an accident.

**Prevention of Accidents for the Future**

There are many suggestions for how heavy truck accidents can be prevented in the future. The first is educating the drivers and trucking companies about the effects of resonance, loading and friction, and road surface condition. Making the drivers more aware of the possibilities and consequences of inclement weather on the road may incline them to take precautions in these conditions and slow their vehicles down. Or if the conditions are really bad, perhaps even take the vehicles off the road.

On the technological side, another solution is devices measuring crosswinds and yaw angle could be installed on the heavy truck. When the yaw angle exceeds a specified point, the driver is notified in the cab by a light or an analog needle and could be an excellent indicator in telling the driver when to slow down the vehicle. When the vehicle is under control again, the truck could speed up again.

The crosswind measuring device could be a good indicator to the driver of whether the trailer is likely to yaw and also give a ballpark figure for the maximum safest speed the truck could drive at.

Neither of these suggestions may sound appealing to both the drivers and trucking companies at first because slowing the vehicles down or taking them off the road means time and money is lost in doing so. Furthermore, the cost of installing and maintaining these measuring devices may be high initially. However, the cost of trucking accidents is high both to the government and to the companies and a tradeoff needs to be considered to ensure better road safety.