Aerodynamics of Train in Overturn Process under Crosswind

Tianyun Dong and Mu Zhong

ABSTRACT

Overturn could happen if train is subjected to strong wind. Numerical simulations were conducted in order to simulate the flow around train when subjected to cross wind with several overturn angles. Non-linear trend of rolling moment was obtained, and the lateral forces and lift have different impact on the moment. The location of maximum positive pressure and minimum velocity moved from side surface to the bottom surface with overturn angle increased. Flow separation velocity is lower at big overturn angle because of the slant surface.

INTRODUCTION

Cross wind have a significant impact on train safety, and mounts of overturning accidents happened because of strong wind, as [1-4]. Therefore, a lot of emphasis has been put on the train running under crosswind environment, from the flow field around train to the dynamic behavior to safety measures like the wind breaks and operation rules and so on, as [5-11]. However, some issues still remain unclear and need further investigation to have a more deep understanding of train behavior after train reached the critical overturn condition. Therefore, this paper focuses on train state under different overturn stage. Cases were studied by numerical simulation, and the differences of flow field and the rolling moment as well as the overturn process will be discussed.
NUMERICAL MODEL, MESH AND SETUP

2d model is used in present work, thus the train section is used for the numerical computational model, as shown in Figure 1. The center of rotation is leeward side rail/wheel contact point, $\theta$ defined the overturn angle. Considering the train cross section shape, the maximum overturn angle is 63°.

The computational domain used in the present work is shown in Figure 2. The inlets provide a steady, uniform velocity profile, where the $u=40m/s$. the ground plane and train body are no-slip moving wall. The outlets are zero-pressure outlets and the roof is set as symmetry. The Reynolds numbers (Re) of the simulations are $1.1 \times 10^7$, based on the height of the section and u.

In current work, the k-epsilon two equations turbulent model is adopted to solve the flow field around the train. This method has been widely applied to simulations of the aerodynamic performance of trains under crosswind, as in [7, 10-11].

The meshes are dominated by polyhedral elements where the mesh size at train surface is 0.1m. To ensure that the velocity gradients near the wall were correctly represented four prism layer cells were applied to the surface of the vehicle. The $y+$ over the majority of the train's surface is under 150.

Mesh sensitivity testing was conducted in order to determine whether the solutions are a function of mesh density, meshes as in Figure 3. The aerodynamic forces and rolling moment, for the coarse, medium, fine and fine1 meshes, in the 0° overturn angle case, are shown in Table 1. The agreement between the results from the medium, fine and fine1 mesh densities indicates that the majority of the important energy-containing flow feature has been resolved and that a finer mesh is not required. Consider the precision and efficiency, following study is based on fine1 mesh setup.

![Figure 1. Train section model: (a) Normal condition, $\theta=0$; (b) Overturned condition, $\theta=63^\circ$.](image-url)
Figure 2. Computational domain used for the simulations.

Figure 3. Computational mesh.

TABLE I. AERODYNAMIC RESULTS OF DIFFERENT MESHES.

<table>
<thead>
<tr>
<th>Mesh element</th>
<th>Lateral force (N)</th>
<th>Lift (N)</th>
<th>Rolling moment (N· m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>coarse</td>
<td>8939</td>
<td>2295</td>
<td>1096</td>
</tr>
<tr>
<td>medium</td>
<td>10655</td>
<td>2460</td>
<td>1118</td>
</tr>
<tr>
<td>fine1</td>
<td>14230</td>
<td>2493</td>
<td>1077</td>
</tr>
<tr>
<td>fine2</td>
<td>34521</td>
<td>2485</td>
<td>1103</td>
</tr>
</tbody>
</table>
RESULTS

The rolling moment and forces at different overturn angle are shown in Figure 4. The moment and forces are all magnified to 25 times original value, for the length of vehicle is 25m. Rolling moment experienced a slowly changing before 10 degree, Figure 4 (a), then increasing rapidly to 15 degree. After that, nearly linear decreasing can be observed. Compare with the lateral forces and lift, in the first stage, lateral forces are changing slowly while lift increased significant. Then lateral forces increased and lift decreased rapidly, same degree as the moment sudden changing. It can be found that before 15 degree, the change trend of lateral forces and moment was consistent, while lift went the opposite direction. Between 15 to 25 degree, lateral force has little changed while lift and moment still went to opposite direction. After 30 degree, forces and moment both decreased with overturn angle.

Split the whole overturn process to 3 stages to analysis. First stage is 0 to 10 degree, the moment changing in a small mount. Second stage is 10 to 15 degree, moment increased to maximum. Third stage is after 15 degree, the rolling moment is continuous decreasing. Lateral force contributed much effect on rolling moment, which is generally known, but it seems that lift has different effect on the moment. In the first stage, as Figure 4 (b), the lift changing a lot but have a small influence on the rolling moment. In the second stage, it still seems reasonable to consider the lift do not affect the moment since the lateral force and moment have a similar increasing. However, the lift after 10 degree is significant smaller than before, and changed little after a rapid decreasing till 15 degree. Therefore it is also reasonable to consider the lift is starting to affect the moment after 10 degree, which is not reflected in the moment because of the steady value. The third stage, consider the forces from 15 degree to 25 degree, where lateral forces almost stay the same value while lift increasing, but it can be found that the moment start to decrease at this region. So it can be sure that the lift is the main reason to moment changing. Compare with the lift condition in second stage, it still not clear whether lift is contributing to moment at second stage. It would be clear if the moment of lateral forces and lift can be split to analysis individually. However, for the technical problem, author did not find a way to analysis the individual moment generated by each force at current time. Lift start to decrease after 25 degree, but lateral force has little changed from 25 to 30 degree. It is interesting to find that although moment is continuous dropping, lift increasing first then decreasing while lateral force little changed. Therefore, lift generated the recover moment, which means a moment has an opposite direction to rolling moment, from 15 to 25 degree and overturn moment from 25 to 30 degree. After 30
degree, both forces are decreasing, but the decreasing of lateral force has a more significant impact on the moment than lift.

![Figure 4. (a) Rolling moment; (b) Lateral forces and lift.](image)

![Figure 5. Colour plot of static pressure.](image)
Figure 5-6 gives the pressure and velocity field around the train. Windward side of vehicle almost is under large positive pressure, as in Figure 5, while the top corner is under negative pressure because of the flow acceleration, shown in Figure 6. With overturn angle increased, the negative pressure on top corner can be smaller due to the weaker flow separation on inclined surface. Meanwhile, the pressure on bottom surface would be larger. In common sense, the lift should decreasing with the deceasing negative pressure on top corner, and increasing with the increasing positive pressure on the vehicle bottom. Thus the lift is possible to have different trend with increasing overturn angle. The maximum positive pressure location at windward side surface moved from center of side surface to bottom surface as the overturn angle increased, same with the low velocity at same side. Also, the positive pressure, or low velocity, at windward surface almost appeared at same vertical level in coordinate system, which can be explained as the vertical flow blocking center because of shape.

**CONCLUSIONS**

This paper presented results from numerical simulations of flow field around a train subjected to cross wind and various overturn angles was considered. From the data presented the following conclusions are drawn:

- Rolling moment changing processes can be split to three stages: steady, rapid increasing and decreasing.
- Rolling moment has a similar trend with lateral forces, while lift can has positive and negative effect on moment at different angle.
The maximum positive pressure, and minimum velocity, location moved from side surface center to the bottom surface with overturn angle increased. Flow separation velocity is lower at big overturn angle because of the slant surface. However, consider the influence of lift remains unclear at second stage, which is ranged from 10 to 15 degree, further works are necessary.

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REFERENCES

