The Application of Aerodynamics in the Design of Double-Decker Container Vehicles

Simei Zhang, Xue-mei Guan and Wujian Wang

ABSTRACT

In the double container car size overrun, the center of gravity high, angular shape characteristic, according to the aerodynamic load of vehicle dynamics, and the influence of intensity method and the mechanical model, studied the aerodynamic load of double container car mechanics index and application in vehicle design method, using the aerodynamics of wind environment and climate and the intersection under the condition of high speed passenger cars are double container car for the analysis of aerodynamic load, and the vehicle dynamics and simulation analysis of car body strength, to test the double container car running safety and stability, and in the original railway line running test organization, double container car aerodynamics performance has been further validation.

Key words: aerodynamic load application of aerodynamic container vehicle

1. INTRODUCTION

Double container car is set on the container, and the cascade of new type of transport vehicles, compared with the single container car, transport capacity can be improved by about 40%, reduce transport costs about a third, is a revolution in the history of container transport.

But compared with the ordinary vehicles, double container car high center of gravity, high speed and ultra-high goods, lateral windward area is large, the wind
climate environment and with the high speed passenger car encounter, will produce a larger aerodynamic load, vehicle running safety and stability, and to the standards of railway freight of our country is not the application of aerodynamic load specification. To this end, through cooperation with Central-South university, Southwest Jiaotong university, has carried out air dynamics in the application of the double container car design technology research, for the application of aerodynamics in railway truck has carried on the exploration of theory and practice.

2. INTRODUCTION TO DOUBLE DECK CONTAINER VEHICLES

X2K, X2H type double container car is for railway leap-forward development, in 2003, has developed China's first generation, is also the Asian first developed successfully and put into use double container transport vehicles.

The car adopts the concave bottom structure, the lower layer container is loaded in the concave bottom, the lower layer container loads in the lower container, the container double layer stack. The lower layer is loaded with 20ft and 40ft international standard boxes, with the upper loading 20ft, 40ft, 45ft international standard box or 48ft, 50ft and 53ft container, as shown in fig.1. Double - headed locking is used in the upper and lower containers.

![FIGURE 1. X2K and X2H double deck container vehicles.](image)

The main technical parameters of the vehicle are as follows:

Gauge (mm) : 1435  
Axle weight (t) : 25  
Load (t) : 78  
Self-weight (t) : 22  
Business speed (km/h) : 120  
Braking distance (heavy car, emergency) (m) : \( \leq 1400 \)  
Vehicle length (mm) : 19466  
Vehicle spacing (mm) : 15666
The high of low point of the car body to rail (empty car) (mm): 190
The high of top of the container to rail (mm): 5807

Packing condition:
Working condition 1: two 20ft container in the lower layer, one 40ft ~ 53ft container in the upper layer, with total load of 78t
Working condition 2: one 40ft container in the lower layer, one 40ft ~ 53ft box in the upper layer, with total load of 61t
Working condition 3: two 20ft boxes in the lower layer and two 20ft boxes in the upper layer, with total load of 78t

3 DESIGN OF AERODYNAMIC LOAD PARAMETERS FOR DOUBLE-DECK CONTAINER VEHICLES

As the ultra-high and over-limit two-level container, the vehicle has a high center of gravity, the shape of the vehicle is sharp and angular, and the aerodynamic flow field is complicated. In the intersection of high-speed passenger train, a transient pressure shock wave is formed for the two-layer container flat car; When working with the horizontal wind, the air pressure difference between the windward side and the leeward side of the container will be high.

To reflect in the double container car design aerodynamic effect, the SEC pressure wave and the air pressure difference by integral synthesis of side force $F_y$, lift $F_z$, roll torque $M_x$ aerodynamic load and overturning moment $M_r$ around the wheel/rail protection, including: $M_r = M_x \times 0.718 - 3 F_y$. See figure 2.

Lateral force $F_y$, lift $F_z$, roll torque $M_x$ aerodynamic load on double container car design as the car body strength and vehicle dynamics simulation analysis of the external turbulence, overturning moment $M_r$ is the external load of vehicle stability checking.

![Figure 2. Aerodynamic load index parameters of double - deck container vehicles.](image-url)
4 CALCULATION AND ANALYSIS OF THE AERODYNAMIC LOAD OF DOUBLE DECK CONTAINERS AT THE INTERSECTION OF THE TRAIN

Train intersection pneumatic impact load analysis and calculation of 40 ft container is under the double container loading, the lower load 45 ft container, in order to speed 120 km/h and DongFeng 11 locomotive traction speed of 160 km/h passenger train intersection, intersection line between 4 m and other conditions. The computer FLUENT6.0 is used to calculate the numerical computation of large commercial flow field of FLUENT company.

Flow field calculation results show that when the locomotive head drove up to the front of container flat car, intersection side in the front of the negative pressure, the rest are mainly positive pressure, the lateral aspect of intersection are mainly negative pressure, the synthesis effect was greatly to make the container flat car lateral exclusive side force + Fy, as shown in figure 3.

![FIGURE 3. Flow field pressure distribution diagram of locomotive head near the intersection.](image)

When locomotive sailed to the container flat wagon at the back of the head, the intersection and the lateral side of container flat car, mainly negative pressure, and the inside of the negative pressure is greater than the absolute average below the outer surface, the synthesis effect makes the container flat car in the first quarter was very attracted to intersection side effect of lateral force - Fy, as shown in figure 4.

![FIGURE 4. Flow field pressure distribution diagram of locomotive head leaving the intersection.](image)
Double-deck container trains for growing group. As the length of the train increases, the thickness of the surface air layer increases, and the pressure amplitude increases accordingly. Because of the vertical space between container flat car more passenger trains many, the intersection side when the train intersection airflow easy escape from the vertical space between container flat car, conductor direction stress wave amplitude is most ΔP one hundred m increases by 4%.

According to the calculation, double-stack trains at 120 km/h speed and dongfeng 11 locomotive traction passenger trains at 160 km/h speed when the intersection pneumatic impact load as shown in table 1, pneumatic impact load and rendezvous time relationship as shown in figure 5.

### TABLE 1. THE AERODYNAMIC IMPACT LOAD OF A DOUBLE-DECKER CONTAINER VEHICLE AT THE INTERSECTION OF THE TRAIN.

<table>
<thead>
<tr>
<th>Pneumatic impact load</th>
<th>Fy(N)</th>
<th>Fz(N)</th>
<th>Mx (Nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of strength</td>
<td>-24546～20069</td>
<td>3735～-4974</td>
<td>-4807～2045</td>
</tr>
</tbody>
</table>

![Graph showing the relationship between the aerodynamic impact load and the intersection time of a two-layer container vehicle.](image)

**FIGURE 5.** the relationship between the aerodynamic impact load and the intersection time of a two-layer container vehicle.
5 CALCULATION AND ANALYSIS OF THE AERODYNAMIC LOAD OF DOUBLE-LAYER CONTAINER UNDER HORIZONTAL WIND

The flow field of the horizontal wind was calculated using CFX 5.3 of the large commercial flow field of AEA in the UK, and the calculation area was 140m, width of 100m and height of 35m.

Central south university of calculation show that the transverse wind flow around container flat car is a kind of very complex three-dimensional flow, from horizontal to bypass the roof in the middle of the container flat car air flow around the vehicle kona produce larger vortex, and the vertical space between container flat car is very big, made from the container flat car end longitudinal gaps around the air flow around, at the top of the vehicle and lee side. See figure 6.

![Figure 6. Flow field pressure distribution of double deck container vehicles under horizontal wind.](image)

The container has a positive pressure on the side of the windward. Due to the circumfluence of air flow, the side of the leeward side is negative pressure, so the vehicle is subjected to greater lateral force.

Floor basically is negative pressure at the top of the container and vehicles, but the top of the negative pressure big, small bottom pressure, from the top of the container with fusion lift and vehicle bottom by the superposition of the old Trafford lift, to the entire vehicle is lift.

When the lower layer 40ft container and the upper 53ft container, the aerodynamic load relations under the horizontal wind action are as follows:

- Lateral force(N): \( F_y = 53.228 \times (v^2 + u^2)C_y \)
- Lift force(N): \( F_z = 53.228 \times (v^2 + u^2)C_z \)
- Over turning moment(N): \( M_x = 155.6 \times (v^2 + u^2)C_m \)

式中：\( C_y \)—coefficient of lateral force, \( C_z \)—Lift coefficient of lift force, \( C_m \)—coefficient of over turning moment.
The relationship curve of Cy, Cz, Cm and wind Angle $\beta$ ($= \arctg \left( \frac{u}{V} \right)$) is shown in figure 7.

![Figure 7. The aerodynamic load coefficient and the wind Angle diagram of the double-decker container vehicle.](image)

After the polynomial fitting, the aerodynamic load coefficient of the double-layer container car under the influence of the horizontal wind is as follows:

\[
C_y = -0.0000048 \cdot \arctg^3 \left( \frac{V}{u} \right) + 0.000467974 \cdot \arctg^2 \left( \frac{V}{u} \right) + 0.01600173 \cdot \arctg \left( \frac{V}{u} \right)
\]

\[
Cz = -0.00003063 \cdot \arctg^2 \left( \frac{V}{u} \right) + 0.00312951 \cdot \arctg \left( \frac{V}{u} \right)
\]

\[
Cm = 0.00001941 \cdot \arctg^2 \left( \frac{V}{u} \right) - 0.00222000 \cdot \arctg \left( \frac{V}{u} \right)
\]

When the speed of the double deck container vehicle is 120km/h and the horizontal wind speed is 25m/s, the aerodynamic load of the vehicle is shown in table 3 below:
TABLE 3. AERODYNAMIC LOAD OF DOUBLE DECK CONTAINER VEHICLES UNDER HORIZONTAL WIND.

<table>
<thead>
<tr>
<th>Pneumatic load</th>
<th>Fy(N)</th>
<th>Fz(N)</th>
<th>Mx(Nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of strength</td>
<td>89270</td>
<td>7475</td>
<td>-16427</td>
</tr>
</tbody>
</table>

6. TEST VERIFICATION OF AERODYNAMIC LOAD

To verify the accuracy of the aerodynamic load of the double container car simulation analysis, to ensure that the double container car transportation safety, the original railway organization in railway and Beijing-Guangzhou route, JiaoJiXian open wire aerodynamic load test, in line with chongqing tunnel aerodynamic load test. Among them, the maximum intersection speed of the Beijing-Jiao line is 242km/h, the maximum intersection of the Beijing-Shanghai line is 175km/h, and the maximum intersection of the JiaoJi line is 330km/h. See figure 7.

Central south university has conducted a full test of the air pressure wave on the Beijing-Shanghai line and the Beijing-Shanghai line. The test and monitoring of the vehicle dynamics were carried out.

FIGURE 7. Test of double-deck container vehicles in Beijing-Jiao line, Beijing-Guangzhou line, JiaoJi line and sui-yu line.
Through aerodynamics and vehicle dynamics testing, the overturning coefficient of the vehicle and the load reduction rate meet the requirements of GB5599-85 in the operation process, and the performance of the two-layer container vehicle is stable.

On the Beijing-9th line, when the double-decker container vehicles are at a speed of 125km/h and 117km/h, the maximum pressure amplitude is 489pa, the maximum transverse impact is +13927N ~ -11806N. On the Beijing-Shanghai line, when the double-decker container vehicle is at a speed of 80km/h and 95km/h, the maximum pressure amplitude of the intersection is 626Pa, the maximum transverse impact is +19831N ~ 18037N.

The test results show that the test results are consistent with the simulation analysis results and the simulation results are verified.

7 THE APPLICATION OF PNEUMATIC LOAD OF DOUBLE DECK CONTAINER VEHICLES

7.1 The application of aerodynamic load in finite element calculation of body strength

Double container car at 120 km/h speed with 160 ~ 250 km/h bus or train intersection, due to the flow field, pneumatic impact load (lateral force F_y, lift F_z, side rolling moment M_x) the size of the changes over the rendezvous time and direction. Due to the high speed train intersection, single section double container car with single section of intersection time very short (about 0.1 ~ 0.25 S), the biggest impact load can be considered a role in the whole vehicle side at the same time, equivalent to the working condition of the stress condition of railway vehicle. While under the effect of horizontal wind, the double container car speed v with wind speed u overlay, form stability in flow field under the action of pressure difference, the aerodynamic load along with the change of speed, horizontal wind speed change, has nothing to do with the role of time, the pneumatic load is equal to the force conditions of the first condition of railway vehicle.

The aerodynamic load is based on the finite element analysis of the vehicle strength, and on the basis of TB/T1335 "specifications for the design and test of railway vehicle strength".

At the intersection of the train: vertical static, dynamic load + aerodynamic impact load, are evaluated to the second working condition.

Horizontal wind conditions: aerodynamic load + centrifugal inertia force +
longitudinal plus (compression) load + vertical static, dynamic load + torsional load, are evaluated to the first working condition assessment.

7.2 The application of aerodynamic load in vehicle dynamics simulation analysis

On the basis of the normal excitation of the operation of the American V class track spectrum, and the aerodynamic load, to meet the requirements of GB5599 specifications for the dynamic performance of school nuclear vehicles.

The train intersection: the various excitations of the normal operation of the double-deck container vehicles and the pressure wave that changes with time to verify the dynamic performance of the vehicle during the intersection.

Under the condition of horizontal wind: all kinds of excitations of normal operation of double-deck container vehicles are added to the aerodynamic loads under transverse wind speed to verify the dynamic performance of vehicles under the influence of horizontal wind.

After the simulation calculation of Southwest Jiaotong University, the dynamic performance of the two-layer container vehicle is as follows:

1. In the case of horizontal wind, the loading coefficient of the vehicle is less than 0.8, and the wheel weight loss ratio is less than 0.65, which meets the requirements of gb5599-85. If the lower layer is empty box, the upper layer is heavy box or upper and lower are empty boxes, then the overturning coefficient will be greater than 0.8, and the possibility of overturning. Or when the speed is greater than 100km/h, the weight reduction will be greater than 0.65, exceeding the allowable standard of gb5599-85. Therefore, in this case, the running speed should be limited to below 80km/h.

2. At 120 km/h on straight line running with the speed of 160 km/h passenger train SEC, under the effect of aerodynamic load, to & heavy next, light box in the way of packing, vehicles of various safety indexes in GB5599-85 safety scope. If the two layers of 40ft are installed with the passenger train, the reload reduction rate will be greater than 0.65, exceeding the allowable standard stipulated in gb5599-85.

3. To & heavy next, light box in the way of packing, in the role of aerodynamic load, vehicle to curve the overturning moment of the medial tipping M are less than zero, so the double-deck container flat car parked on the curve is safe.

4. In order to ensure the safe operation of the double deck container, the lower
layer is empty box, the upper layer is heavy box or upper and lower layer are boxes of empty boxes as far as possible. In this way, train speed should be strictly limited.

8 CONCLUSION

(1) The aerodynamic load of aerodynamics was applied to the vehicle design, which improved the safety and reliability of the double-deck container vehicle, and ensured the performance stability of the two-layer container vehicle.

(2) The first application of aerodynamics to the design of railway freight cars has been beneficial, which can be used for reference for the improvement of railway freight truck design theory and design specification.