Moving Model Analysis of the Slipstream of a Multiple Group Type High-Speed Train

Yi Guo, Dilong Guo and Guowei Yang

ABSTRACT

Based on a 1:8 scaled moving model rig and a model of high-speed train (HST), the slipstream of 3~8 group type model was measured and studied at the train speed of 57m/s with a scaled moving model technique in a train aerodynamic experiment. The group type impacting on slipstream was analysed. The location and magnitude of the local leading nose peak, the local trailing nose peak and the near-wake peak of slipstream with different group type were calculated and classified. A detailed analysis was conducted on the change of slipstream with the change of group type. The results are helpful to the optimized group type in model experiment of HST’s slipstream.

Key words: moving model; high-speed train; slipstream; aerodynamic experiment; group type

1. INTRODUCTION

The slipstream is the air flow induced by the train’s passing, which has a negative effect on the environment around the high-speed train (HST). With the speed of HST improving, the HST’s movement can induce huge air flow, which presents the risk of hazards to track-side workers and facilities. The slipstream...
induced by movement of HST has become an important content of train aerodynamics and a critical aspect of safe operation.

The moving model methodology is acknowledged as a valid technique for analysing slipstream of a HST. The moving model of HST can simulate the moving state of full-scale train completely and has the advantage of train-ground relative motion as full-scale train, also voiding the interference of ambient wind in the measuring of slipstream. The train-ground relative motion affects the process of generating wake of the train, so that moving model can capture the feature of slipstream more directly and accurately than wind tunnel experiment.

The flow around HSTs is highly three dimensional. Moving train can induce two flows with different directions: ‘accelerated’ flow and ‘entrained’ flow, as presented in Figure 1. Accelerated flow is opposite to the direction of train’s movement, and is primarily around the head and tail. Entrained flow travelling with the direction the train’s moving, generally exists over the roof, sides and wake and developing with the thickening boundary layer up to maximum width in the wake. The slipstream profile shown in Figure 1 is measured from a line paralleled to the direction of a train’s moving. There are three parts can be divided from the slipstream profile: local nose peak, region of developing slipstream along train’s body and near-wake region. These features of slipstream are identical to Baker’s description about flow around HST[1]: The flow have three distinct regions — the nose, boundary layer and wake regions.

![Figure 1. The slipstream of a high-speed train.](image-url)
The distance between probes and train side has obvious influence on slipstream measurement as same as the height of probes above ground. Dilong Guo’s result of numerical simulation about slipstream [2] shows that the probe closer to the train side, the perturbations caused inter-carriage gaps to slipstream profile are more distinct. Different location of probe leading to different slipstream also shown in Sterling’s [3] full-scale experiments and Hemdia’s numerical simulations [4].

J.R. Bell has done plenty of research about slipstream: the dominant frequencies of a pair of streamwise, counter-rotating vortices have identified in the near-wake of high-speed trains in wind tunnel experiments [5]. The relationship between the length of streamline part of trailing car and the near-wake peak was accessed by using different tail geometries of ICE3 in wind tunnel experiments [6]. Using the scaled moving model technique, the sensitivity of slipstream to two factors, Reynolds number and length to height ratio (L/H), has contrasted and the TSI compliance of slipstream has checked [7].

This paper is base on the J.R. Bell’s conclusion about slipstream of HST, testing and analysing the feature of slipstream of a multiple group type HST for further research. The results of measurement analysed through ensemble averaging to find out the feature and variation of the slipstream induced by different group type’s HST.

2. METHODOLOGY

2.1 Experimental facility

The experiment was performed at Advance Railway Mechanics Center (ARMC), Institute of Mechanics, Chinese Academy of Sciences at Hairou, Beijing. The moving model rig (MMR) is 264m long and scale ratio is 1:8. There is a 120m test section of MMR, as shown in Figure 2. The velcovity-measuring system consisted of laser and photoelectric sensor was used to determine the model’s velocity. The model’s velocity was used to convert the result measured from the time domain to the spatial domain, in which the results are analysed. The light casted from velcovity-measuring system was parallel to hot wire S1 probe, and they had the same location in the direction of moving model head for. The ground digital acquisition system synchronize the velcovity signal and anemometers signal, so that locate where the leading nose of model passing by the anemometers in the slipstream profile.
A 1/8th scale model of a CR400AF, a HST of the China Standardized EMU, used in the experimental work.

![Image](image.png)

**Figure 2.** The moving model rig of high-speed train.

### 2.2 Location of probes

Slipstream velocities were measured by hot wire anemometers. The location of hot wire anemometers is compliant with the TSI and EN14067: each probe had longitudinal spacing of 2.5 m (20 m full-scale), as shown in Figure 3. These probe were single hot wires located at 375 mm from the center line of MMR’s rail and at 25 mm above top of rail (equivalent to full-scale \( y = 3 \text{ m}, \ z = 0.2 \text{ m} \) above top of rail).

![Image](image.png)

**Figure 3.** The location of hot wires.

The sampling frequency of hot wires were set up at 10000 Hz, corresponding spatial resolution of 5.7 mm. These probe were mounted parallel to the ground and perpendicular to the train side, as shown in Figure 4. The single hot wires anemometers as shown in Figure 5. This gave the resultant of the \( u \) and \( v \) components of velocity, thus horizontal velocity, which is defined herein as \( U \). A type of slender rod support to mount hot wires for avoiding the support prohibits the measurement of accelerated flow around the train’s nose so that a double nose peak apparent in the slipstream profile.
2.2 Text scenarios

Six scenarios were tested, indicated in TABLE Ⅰ. The speed of model in the test section of MMR is 57m/s (width as characteristic length, \( \text{Re} \approx 1.9 \times 10^6 \)).

<table>
<thead>
<tr>
<th>the group type</th>
<th>length of model</th>
<th>length to height ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 car model</td>
<td>10.087m</td>
<td>20</td>
</tr>
<tr>
<td>4 car model</td>
<td>13.294m</td>
<td>26</td>
</tr>
<tr>
<td>5 car model</td>
<td>16.501m</td>
<td>33</td>
</tr>
<tr>
<td>6 car model</td>
<td>19.708m</td>
<td>39</td>
</tr>
<tr>
<td>7 car model</td>
<td>22.915m</td>
<td>45</td>
</tr>
<tr>
<td>8 car model</td>
<td>26.119m</td>
<td>52</td>
</tr>
</tbody>
</table>

3. RESULTS

3.1 Correlation test

According to Baker’s method for testing correlation [8, 9], the independence of the result measured by S1～S4 probes can be check. The correlation between the probes was investigated by comparing the magnitudes of the maximum of each individual run, plotting scatter of each pair probe’s maxima, as shown in Figure 6. If the maximal magnitudes for individual run measured by different probes were same, the point would lie on the 1:1 line, implying 100% positive correlation between the two probes. With comparing, the correlation rarely exists among the probes, thus the measurements of S1～S4 probes are mutual independence. This effectively multiply the number of real runs performed, thus ‘run multiplication’.
Each scenario processed 16 effective runs.

![Graphs of correlation among S1~S4 probes](image)

Figure 6. With six moving model scenarios tested, the correlation among S1~S4 probes. Black line: 1:1 line, where points would lie if runs were highly correlated. Black squares: 3 car model maxima, red squares: 4 car model maxima, blue squares: 5 car model maxima, pink squares: 6 car model maxima, green squares: 7 car model maxima, orange squares: 8 car model maxima

### 3.2 Analysis of slipstream in the developing reign with different group types

Corresponding the leading nose to x =0 m and the trailing nose to x =0 m respectively, the state of slipstream before the near-wake region in the spatial domain are presented. In the region of 3 car model length (10.09 m), the feature of ensemble average profiles of different group types were contrasted, as shown in Figure 7.

Deviating backwards from the leading nose 0.15 m (moving model at speed of 57m/s), the slipstream have stable local nose peaks, variable magnitude of peak due to different group types, as shown in TABLE II. The magnitude of the local nose peak declines as the group number grows, and the range of decreased velocity of peaks is 11.22%.

Before the first inter-carriage gap, the slipstream profile of 3 car model is obvious higher than other group types’. At the middle of the middle car (3.45 m~6.65m) the velocity of slipstream change from high to low, and remain fluctuating at a centre velocity of 1.34 m/s. The other group types’ slipstream increase generally after local nose peak, have no tendency of decline before 10.09 m. Besides, as the group number grows, the slipstream increasing slowly and having low fluctuation, before 10.09 m.
The velocity of slipstreams increasing with the developing boundary layer along the length of the train, and local peaks appeared before the trailing nose. After local peaks the velocity decline down to the trough at trailing nose. TABLE III shows that the group type (thus L/H) impact the magnitude of local trailing nose peak: as the group number grows, the magnitude of local trailing nose peak increases.

![Figure 7. The slipstream profile of different group type in the developing region](a) (b)

Black line: 3 car model, red line: 4 car model, blue line: 5 car model, pink line: 6 car model, green line: 7 car model, orange line: 8 car model.

**TABLE II.** The local leading nose peak of different group type.

<table>
<thead>
<tr>
<th>the group type</th>
<th>3 car model</th>
<th>4 car model</th>
<th>5 car model</th>
<th>6 car model</th>
<th>7 car model</th>
<th>8 car model</th>
</tr>
</thead>
<tbody>
<tr>
<td>U of local peak (m/s)</td>
<td>4.68</td>
<td>4.59</td>
<td>4.44</td>
<td>4.54</td>
<td>4.16</td>
<td>4.41</td>
</tr>
</tbody>
</table>

**TABLE III.** The local trailing nose peak of different group type.

<table>
<thead>
<tr>
<th>the group type</th>
<th>3 car model</th>
<th>4 car model</th>
<th>5 car model</th>
<th>6 car model</th>
<th>7 car model</th>
<th>8 car model</th>
</tr>
</thead>
<tbody>
<tr>
<td>U of local peak (m/s)</td>
<td>1.71</td>
<td>2.49</td>
<td>3.45</td>
<td>3.42</td>
<td>2.68</td>
<td>3.92</td>
</tr>
</tbody>
</table>

### 3.4 Analysis of slipstream in near-wake region with different group types

Corresponding the trailing nose to x =0 m, in the spatial domain, the variational feature of slipstream in the near-wake region are analysed. In the near-wake region, every slipstream of different group types has local near-wake peak, indicated in Figure 8. The location of peak moves backwards as the group number growing, when the group number exceeds 5 (include 5 car model), the location of peak will fix at 7.2m, but the magnitude of peak rarely suffer influence from the variation of
group type and has a stable velocity of 4.4 m/s, as shown in TABLE IV. The 8 car model’s location of local near-wake peak (4.1 m) nearer with zero than others, but a double peak apparent in the local near-wake peak area. The width of near-wake peak also influenced by group type, as the group type grows, the width will present multistep increase: 4~6 car model have analogous width and 7 car model has maximum width, as shown in Figure 9.

![Figure 8. The profiles of slipstream in the near-wake region.](image1)

![Figure 9. The line graph of the width of near-wake peaks.](image2)

<table>
<thead>
<tr>
<th>group type</th>
<th>3 car model</th>
<th>4 car model</th>
<th>5 car model</th>
<th>6 car model</th>
<th>7 car model</th>
<th>8 car model</th>
</tr>
</thead>
<tbody>
<tr>
<td>X (m)</td>
<td>3.32</td>
<td>5.63</td>
<td>7.26</td>
<td>7.26</td>
<td>7.23</td>
<td>4.10</td>
</tr>
<tr>
<td>Y (m)</td>
<td>4.76</td>
<td>3.90</td>
<td>4.34</td>
<td>4.63</td>
<td>3.82</td>
<td>4.85</td>
</tr>
</tbody>
</table>

### 3.5 Analysis of peak location of individual runs with different group types

Ensemble average only presents the time-average feature of slipstream, the maximum of ensemble average profile is just consequence of average, has shortcomings of describing a transient feature. In the spatial domain, which ordinate origin set as position of trailing nose, the coordinates of maxima of individual runs were processed, as shown in Figure 10. The scatterplot shows that 3~5 car model maxima of slipstream exist in x > 0 area, and as the group number exceeds six, the number of maxima of slipstream in the x < 0 area increases. There are about 46% and 42% maxima of individual run in the x < 0 area of 7 car model and 8 car model respectively.
4 CONCLUSIONS

This paper analysed the feature of slipstream of different group types. The conclusions can be present as follows:

(1) As the groups number grows, the magnitude of local leading nose peak of slipstream declines, but the decrease is invisible. The slipstream of 3 car model is distinctly different from others in the developing region of slipstream. The magnitude of local trailing nose peak will increase as the groups number grows.

(2) The location of near-wake peak of slipstream will moving away from tailing nose as the groups length grows, but when the number of group exceeds 5, the location of near-wake will fix at 7.2m away from tail.

(3) The maxima of slipstream are not confined to existing in the near-wake region. As the group’s length grows, the higher possibility of slipstream maxima exist before trailing nose is accessed.

(4) For the scaled model of HST having accurate simulation of slipstream, the group number should exceed five, thus the length to height ratio of model should not less than 33.

REFERENCES


