

# Numerical Investigation of Aerodynamic Characteristics of High Speed Train

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**Abstract.** In this work, initially the effect of nose shape on the drag characteristics of a high speed train is studied. Then the influence of cross winds on the aerodynamics and hence the stability of such modern high speed trains is analyzed. CFD analysis was conducted using STAR-CCM+ on trains with different features and important aerodynamic coefficients such as the drag, side force and rolling moment coefficients have been calculated for yaw angles of crosswinds ranging from 0° to 90°. The results show that the modification on train nose shape can reduce the drag up to more than 50%. It was also found that, bogie faring only reduces small percentage of drag but significantly contributed to higher rolling moment and side force coefficient hence induced train instability.

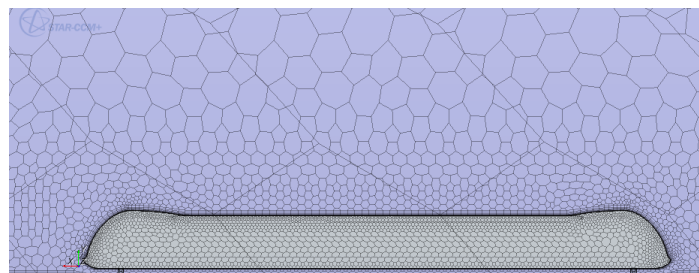
## 1. Introduction

Many of the current generation high speed trains such as the French TGV Duplex and Japanese Shinkansen E6 reach speeds of 300km/h in regular operation. At these speeds aerodynamic forces and moments get amplified and hence it greatly influences the performance of the train. In addition to the high forward speed, strong cross wind may affect the stability and riding comfort of the vehicles and it may cause the train to overturn. Therefore, understanding of train stability under crosswinds is a topic of safety concern in the railway community of every country. Thus crosswind stability of rail vehicles has been a research topic during the last few decades [1-6]. Moreover, to achieve high speeds, the aerodynamic drag of the rail vehicles was decreased using various design features, such as adopting streamlined shape head [7] and also by covering the train bogies using fairing [8], etc. These design features may have an influence on the crosswind stability of the bogies. Thus in this work, the effect of both, bogie fairings and nose shape, on the aerodynamic characteristics was studied together in normal and cross winds conditions. The aim of this study is to modify the train nose into a streamlined shape and also add bogie fairings for the purpose of aerodynamic drag reduction and to investigate the effect of the bogie fairings and nose shape on the aerodynamic characteristics of high speed train under turbulent cross winds.



## 2. Methodology

The CFD analysis on train models with different configuration were simulated in CFD software STAR-CCM+, to study the aerodynamic characteristic of the train such as, drag, lift, moment and side force coefficient. For the study of the cross wind effect on train, a large computational domain is created simulating the wind tunnel working section. In the computational domain, the air flow direction can be changed to meet the required yaw angle for simulation. The physics of the simulation were set up according to that of Biadgo et al [6]. The numerical simulation scenario consists of a stationary train exposed to a constant cross wind of 70m/s at different yaw angles ranging from 0° to 90°. Implicit Unsteady-RANS Method was used with turbulent and K-Epsilon model. On the outlet, a uniform Neumann boundary condition is applied, meaning that the pressure gradient equals zero. The inflow turbulence intensity and length scale were set to be 3% and 0.3m respectively. All runs were performed with a time step of 0.08 sec. Fig 1 shows the side view of the 3-D meshed train with the polyhedral volume mesh around the train.

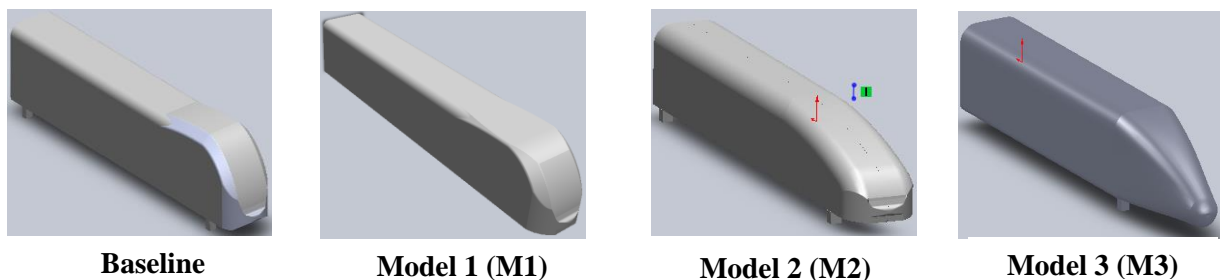


**Figure 1.** Side view of the meshed train and the volume mesh around train with prism layers

## 3. Results and Discussion

### 3.1 Effect of Nose Shapes on Drag and Lift Coefficient

Initially the effect of different nose shape on the aerodynamic performance of the high speed train is studied. Models resembling modern high speed trains with different nose shape were considered for CFD analysis as shown in Fig 2. Baseline train model dimension is chosen based on the Desiro ET425M Train also known as KLIA Express. The major dimensions of Desiro ET 425 M is 50m x 4m x 4.6m. In addition, other train models with optimized nose shape is also chosen for analysis.



**Figure 1.** Train models with different nose shape.

**Table 1.** Drag and Lift coefficient of different models

Model	Drag Coefficient, $C_D$	% change in $C_D$	Lift Coefficient, $C_L$	% change in $C_L$
Baseline	0.532	-	0.471	-
M1	0.544	+2.25%	0.299	+36.5%
M2	0.353	-33.6%	0.263	-44.2%
M3	0.230	-56.8%	0.074	-84.3%

\*negative sign '-' indicating decrement while positive sign '+' indicating increment.

The results obtained from the CFD analysis for different nose shapes are presented in Table 1. We can see that, the M1 has the largest drag coefficient, followed by baseline, M2 and lastly M3. The lift coefficient is highest for baseline model and followed by M1, M3 and lowest M3. The lift coefficient for M3 has been reduced drastically which is more than 50% less than the baseline model.

### 3.2 Effect of Bogie Fairings and Nose shape on the Aerodynamic Characteristics of High Speed Train under Cross winds

The following three models as shown in Figures 3-5 are considered for study on the effect of cross winds at different yaw angles. The CFD results obtained for side force coefficient and rolling moment coefficient for different yaw angles are presented in Figure 6 and Figure 7.



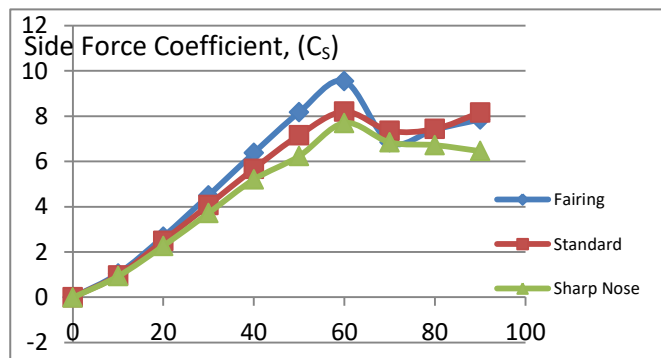
**Figure 3.** Standard model (Without fairing)



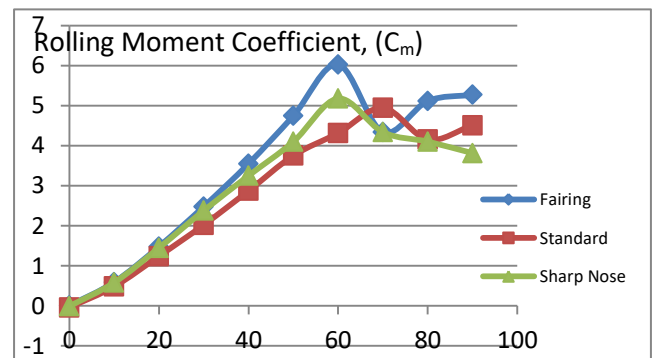
**Figure 4.** Train with fairing



**Figure 5.** Sharp nose train without fairing



**Figure 6.** Side force coefficient vs yaw angle for train with fairing



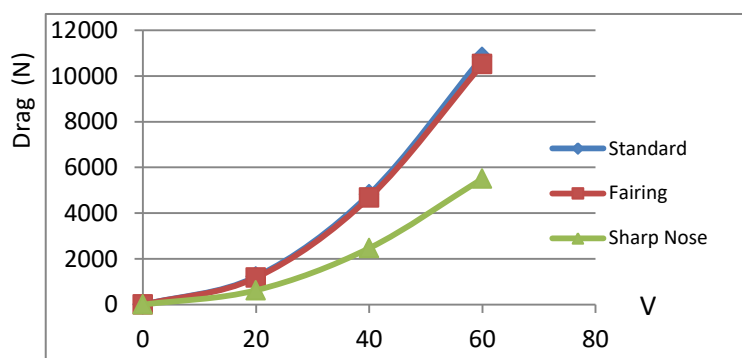
**Figure 7.** Rolling moment coefficient vs. yaw angle

From figure 6, it can be seen that the side force coefficient for standard and train model with fairing increases steadily with yaw angle until 60° before it starts to decrease and increase again after 70° to 90°. From 0° to 60°, the side coefficient value of model with fairings is slightly higher compared to the standard model. However at 70° and 90°, the value of side force coefficient for standard model is slightly higher compared to the model with fairings. On the other hand, the side force coefficient for sharp nose model is lowest compared to other models at every yaw angle.

As can be seen from figure 7, the rolling moment coefficient varies almost in a similar fashion to the side force except that the rolling moment coefficient of standard model is higher than model with fairing only at 70°. The rolling moment coefficient of sharp nose model is considerably lower compared to model with fairing but higher than standard model at every yaw angle. At yaw angle of 90°, the rolling moment coefficient for sharp nose is lowest compared to other models.

In general, the variation of the side force and rolling moment coefficients of the models with and without fairing is in a good agreement with the numerical and experimental results presented by Biadgo et al [6]. It can be seen from Fig 7 that there is a significant rolling moment resulting from the lift and side forces that can lead to overturning of the train with overloading of the railway track as well.

To understand the effect of fairings on the aerodynamic performance of the train, the three models (Figs 3-5) were analyzed at different speeds and the results for the drag force are as given in Fig 8.



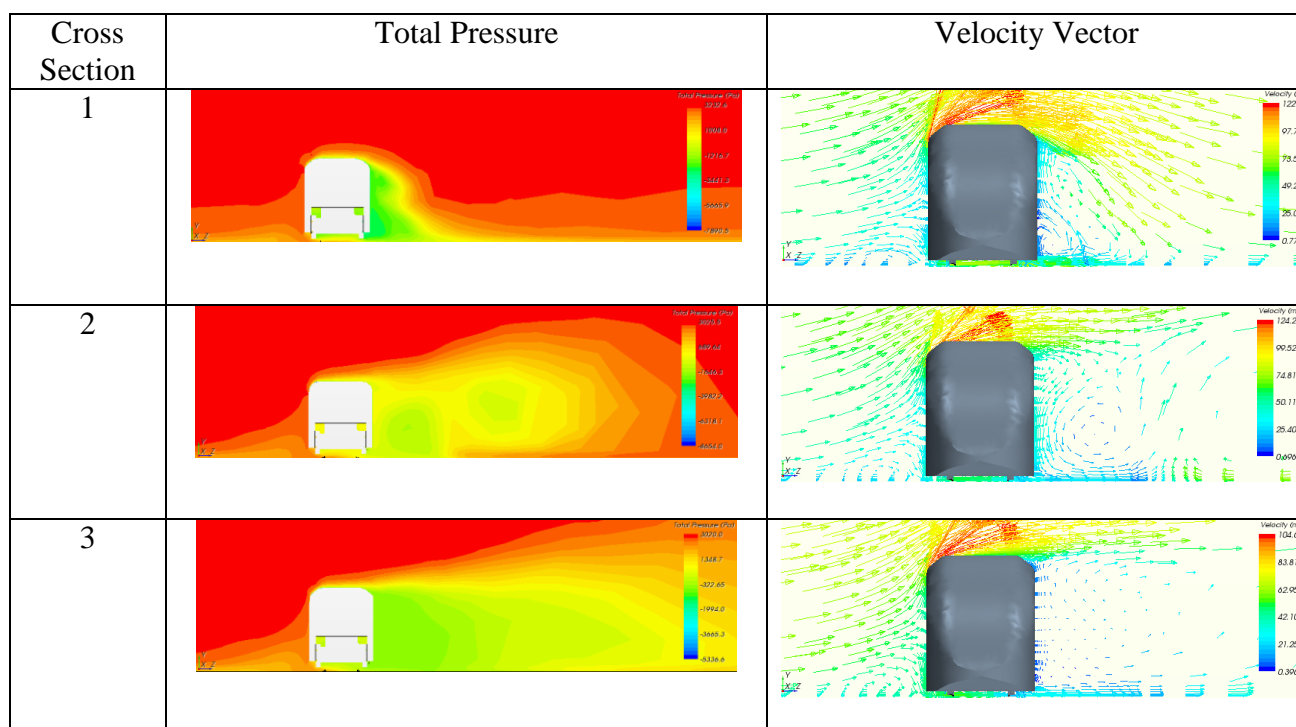
**Figure 8.** Drag force vs. speed of train

It is obvious that the drag curve for the configuration with fairings stands below the curve of the standard configuration and the drag curve for sharp nose model is way below the base model. It was found that the drag reduction by use of fairings is only about 44.6 N (3.6%) at the speed 20m/s and 316.4N (2.85%) at 60m/s.

The drag coefficient ( $C_D$ ) for sharp nose model was lowest at around 0.26 compared to the other two models at 0.5. Thus the fairings at the train bogie reduce the drag of the train by a very small decrement. However, the modification on the nose gives significant drag reduction.

#### 4. Flow Structure

Results have been generated for flow around the train for different yaw angles from  $0^\circ$  to  $90^\circ$  and typical flow structure around the train for a yaw angle of  $60^\circ$  is shown in Figure 9. The flow structures of the trains were taken along the train's cross section at different cutting plane (front, mid and rear end).



**Figure 9.** Velocity vectors, colored by velocity magnitude (m/s) and total pressure contour (Pa) along the standard train's cross section planes for yaw angle  $60^\circ$ .

As can be seen from the figure 9, flow separation takes place on both the lower and upper edges of the bogie. Contours of velocity vectors and total pressure distributions have also been computed at different cross-sections from the nose of the train along its length for different yaw angles. As can be seen in Fig 9, there is a high velocity on the top of the train i.e flow accelerates on the trains' top surface and also the presence of vortex creates a low pressure region. The existence of the lower pressure region explains the increased side force and roll moment. The results obtained are very similar to that of Biadgo et al [6].

## 5. Conclusion

Based on the findings, it can be concluded that, Baseline Model and Model 1 designs can be considered as bluff body design compared to Model 2 and 3. The results of drag coefficient for Baseline and Model 1 are significantly large compared to streamlined shape of Model 2 and 3. A change in train nose design can significantly improve the aerodynamics of high speed train. The study has also shown that, bogie fairing only reduce drag in small percentage but contribute to higher rolling moment and side force coefficient. Thus the bogie fairing can reduce small amount of drag at the cost of higher tendency for the train to be unstable and overturn. A sharper and streamlined train nose will contribute to both drag reduction and give better crosswind stability compared to other models.

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