Aerodynamic loss in Inter-Car Space of Train and its Reduction

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Abstract- This paper carried out a research with the aim is to study the turbulent flow in the inter-car gap of train and reducing the aerodynamic loss in the inter-car gap. The research is carried on Indian train which has the average speed of 20 m/s. The purpose of study was to analyze the aerodynamic loss in the inter-car gap of Indian train. This aerodynamic loss in the gap between two coaches can be reduced using some filler or flat plate. The study is based on cavity flow because the gap between two coaches looks like the cavity. Another analysis also carried on same condition of inter-car gap to reduce the aerodynamic loss on train using some filler (plate), which is same as the study of flow over the flat plate. In the cavitational area vortex is generated due to which the aerodynamic drag increases, by using the plate the formation of vortex can be reduce. ANSYS Fluent 14.5 has been used to solve the governing equations of both the conditions. Before the analysis geometry is drawn on Gambit 2.2.30 software, which is used for the drawing and grid generation. In inter-car space very fine grids are used, which shows the generation if eddy in the gap region. For the analysis k-ε turbulence model is used which gives the better analytical result. The results have been presented for both the condition which shows the better result over the cavity flow in trains. After the study and analysis on Indian train, the aerodynamic loss on the train by using the filler in inter-car gap reduces till 5 – 6 %. This reduction of aerodynamic loss on train for single inter-car space may lead for improvement in Indian train.

Keywords – Inter-car space, Indian Train, Turbulence model, Aerodynamic drag, Drag reduction.

I. INTRODUCTION

Indian Railway is an Indian state owned enterprises operated by Government of Indian. It is one of the world's largest railway networks comprising 115,000 km (71,000 mi). In 2014-15, Indian Railway carried 8.398 billion passengers annually or more than 23 million passengers in a day and 1050.17 million tons freight in a year.

For the development of a faster and safer train system with lower air pollution, low aerodynamic resistance and noise, many researchers are paying much attention on the aerodynamics of railway train. These works have attention to the development of new-generation train body, rail and tunnel systems. The aerodynamic phenomena with regard to train are strongly dependent on the velocity of train. Thus, the aerodynamic resistance problems become more important as the train speed increases.

Now if a small change occurs in trains that will deal with a big profit. Indian trains face max, aerodynamic drag force as compared to engine and wagons of train in other countries due to their old design. Indian railway also lags in terms of analysis of aerodynamics and air flow. Certain problems arise when we compare Indian Railway with the railways of some other countries. In India, average number of wagons is 25 whereas in countries like Australia number goes up to 48. The average speed of trains in India is 20 m/s (72 km/h) including stoppage. The aerodynamic drag is dependent on the cross-sectional area of train body, train length, shape of train, surface roughness of train body, and geographical conditions around the traveling train. The train-induced flows can influence passengers on the platform and is also associated with the cross-sectional area of train body, train length, shape of train fore- and after-bodies, surface roughness of train body etc.

II. AERODYNAMICS FORCES ON INDIAN RAILY TRAIN

The aerodynamic characteristics of Indian train are quite different from the characteristic of other country's train. There are many characteristic features in the aerodynamics of the railway train, in the points that the train length is, in general, very long, compared with the equivalent diameter of it, the train runs close to adjacent structures, passes through a confined tunnel, and intersecting with each other, the train runs along a fixed railway track, always interacting with ground, and the train can be influenced by cross-winds. Thus, the aerodynamics, which has been applied to airplane, may not be of help for a detailed understanding of the HST aerodynamics

In general, a desirable train system should be aerodynamically table and have low aerodynamic forces. These aerodynamic characteristics are closely associated with the aerodynamic drag of the running train. The aerodynamic drag on the traveling train is largely divided into mechanical and aerodynamic ones. The aerodynamic drag can influence the energy consumption of train. Thus, detailed understanding on the aerodynamic drag and its precise evaluation are of practical importance. It has been well known that the aerodynamic drag is proportional to the square of speed, while the mechanical drag is proportional to the speed. Compared with the mechanical drag, the portion of the aerodynamic drag becomes larger as the train speed increases

III. LITERATURE REVIEW

After the analysis of flow around high speed train, Chris Baker [1] does not specifically address the many aerodynamic problems associated with such vehicles, but rather attempts to describe, in fundamental terms, the nature of the flow field. The rationale for such an approach is that the flow fields that exist are the primary cause of the aerodynamic forces on the train and its components which result in a whole range of aerodynamic issues. He analyzes all the aerodynamic region of train weather it is front of locomotive or it is behind the coach.

In the study of flow structure on Indian trains Vivek kumar and Abhishek Pratap Singh [2] analyze the flow structure and finding the high pressure points and suggesting suitable changes to eliminate them by low pressure points and study the velocity pattern of air across the body. In the conclusion he took a glance on the inter car gap of train, according to him there are some low velocity regions between the bogies.

In the application of CFD to rail car and locomotive aerodynamics James C. Paul et.al [3] evaluated the effects of position-in-train and inter-car spacing on aerodynamic drag. For the case of small gaps between adjacent cars, the flow appears to move smoothly from the rear of the upstream car to the front of the downstream car. The flow in the gap region is a trapped vortex that does not interact substantially with the free-stream. Adjacent cars with narrow inter-car gaps thus act as a single body. As gap distances increase, the drag approaches that of multiple, single bodies. He apply his observation in open top bulk materials cars, such as hopper and gondola cars, where vertical baffles have been employed to provide multiple trapped flow regions, thus preventing high speed air from impacting forward-facing surfaces. The simulations in the project of Paul and his team indicate the drag area of the well car decreased from 44.1 ft^2 to 38.1 mft^2 with the addition of the spine containers. However, the spine containers contributed 6.0 ft^2 of drag area, so no net gain was realized at zero degrees yaw.

Alexander Orellano and Martin Schober [5] show the results of wind tunnel experiments on the aerodynamic performance of a generic high-speed train. The wind tunnel model used is a simplified 1:10 scaled ICE21. This so-called “Aerodynamic Train Model” (ATM) is Bombardiers standard train geometry for the validation of numerical simulation methods and for the comparison of results obtained in different wind tunnels. The main motive of study was the effect of cross-wind on the rail coach.

Richard M. Wood [6] discussed on heavy truck and advanced aerodynamic trailer system. In gap treatment design activity [p 4], a vortex-trap device was designed and located on the forward facing front face of the trailer and is termed the Cross-flow Vortex Trap Device (CVTD). The leading edge of the adjacent surfaces comprising the CVTD were made aerodynamically sharp to ensure the gap cross-flow separates at the CVTD leading edge and generates a vortex that is trapped between adjacent CVTD surfaces. The trapped vortices impart a low pressure on the forward facing surface of the trailer. As the gap cross flow develops it encounters the leading edge of the furthest windward CVTD surface and separates at the leading edge forming a vortex that is trapped between the furthest windward surface and the adjacent surface, located immediately inboard. The flow separation at the leading edge of the CVTD induces an acceleration of the flow located immediately forward of the CVTD. This induced flow field is accelerated toward the leading edge of the adjacent surface. These flow characteristics are repeated at each subsequent surface, moving from left to right. The trapped vortices impart a low pressure on the forward facing surface of the trailer.

TIAN Hong-qi [8] analyzes the formation mechanism of aerodynamic drag of high-speed train. According to the methodology of Tian Hong-qi the flow structure around the train was studied by CFD (computational fluid dynamics) simulation method. Three-dimensional Reynolds-averaged Navier-Stokes equations, combined with the RNG (random number generator) k-ε turbulence model, were solved on a multi-block structured grid using finite volume technique. According to him the open air condition, the aerodynamic drag of in the train is the sum of the tangential forces (skin friction drag) and the normal forces (pressure drag), both of which are parallel to the opposition direction of vehicle’s velocity vector.

Fouad Alwan Saleh and Ahmed Kadhim Hussein [10] present work is to develop the computer program to simulate the steady two-dimensional laminar and turbulent flows. The finite volume method is used to solve the flow governing equations numerically. The Navier-Stokes equations are solved for the velocity flow field. Since all the variables are stored at the center of each control volume. The correct velocity field is then used to solve k-epsilon equations. The eddy viscosity, that represents the influence of turbulence on the mean flow field, can be calculated from those values of k and epsilon obtained.

According to Lai et. al [16], the greater the gaps between loads, the larger the aerodynamic penalty because closely spaced containers or trailers behave as one long load. In contrast, loads spaced 72″ or more apart, behave as distinct objects as boundary layers on their surfaces are reinitialized. The wind tunnel tests showed that the lead locomotive experiences the highest drag due to headwind impact. After the head end, resistance declines until about the 10th unit in the train, after which drag remains nearly constant for the remaining unit's gap length and placing loads with shorter gaps near the front of the train will result in lower aerodynamic resistance.

III. Problem Defination

Railcar aerodynamic studies are typically undertaken to improve safety and increase fuel efficiency. As the small modification can gives the change on large scale due to its huge network. So the aim of study is to reduce the aerodynamic drag in the inter-car gap of coaches of train. For this analysis is done on cavity or gap and on a flat plate used as filler between two coaches. This flat plate or filler will reduce the aerodynamic loss on trains. By reducing the drag on coaches, acceleration will automatically increase due which to less power of locomotive require.

IV. Geometrical Setup

The analysis must be an accurate model of a physical prototype in dimension and size. In the broadcast sense, this model should be same in the manners of nodes, elements, material properties, real constants, boundary conditions, and other features that can be used to represent the actual system. The object here is referred to the Indian Railways bogies. Dimension and figures of coach is drawn on the bases of official data of Indian railway. IR coaches' whether it is ICF coach or LHB coach faces maximum aerodynamic drag due to their design. Length over body of Linke Hofmann Busch coach (LHB) is 21,279 mm; width and height of body are 3,125 mm and 3773 mm respectively. Ground clearance of train is 264 mm. Some of the illustrations which display the dimensions are given in Figure 2.

Main motive of the paper is to analyze the flow in inter-car gap and to reduce the aerodynamic drag possessed by the gap. The flow in the gap region is a trapped vortex that does not interact substantially with the free-stream. Adjacent cars with narrow inter-car gaps thus act as a single body. As gap distances increase, the drag approaches that of multiple, single bodies. The generated vortex (eddy) consumes energy of locomotive.

Figure 1: Inter-car gap in Indian train

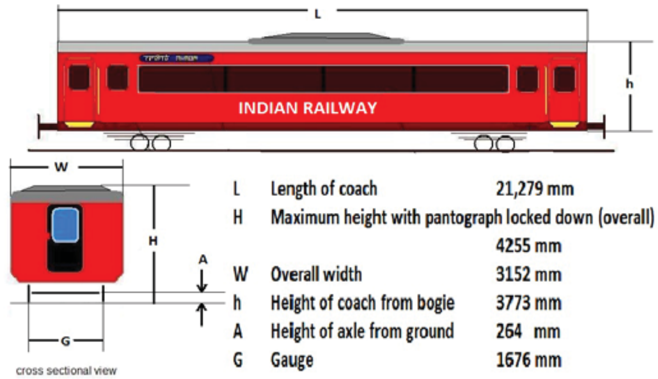

Figure 2: front and side view of Indian train with geometrical dimensions

IV. Computational Setup

The ultimate purpose of a finite element analysis is to recreate arithmetically the behavior of an actual engineering system. Flow in inter-car gap behaves as open cavity which study has been carried out with computational domain shown in figure below. This study has two components –

A. **Flow in inter-car gap -** Figure 3 shows the computational dimension of setup. For the analysis the geometry is drawn in 2 D plane. A domain is created in which the railway coaches are carried. The size of domain is 8.07 D vertically and 18.48 D on horizon. Distance of domain from front face of first coach is 1D and at rear it is 6 D. Length of coach is taken as 5.64 D computationally and height is 1 D. Dimension of inter-car gap is 0.2 D; ground clearance of train is 0.07 D. Inlet boundary is nearer to the wall of coach whereas outlet boundary is far from the wall of coach.

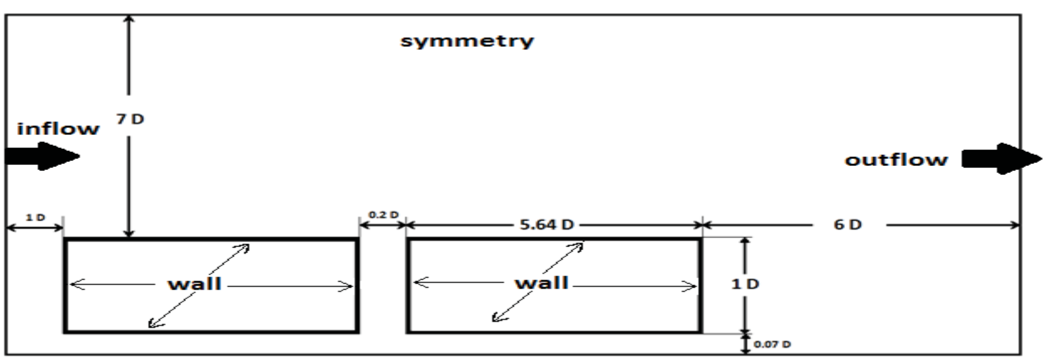

Figure 3: Computational domain of train when inter-car gap is available with dimension (not to scale)

B. *Flow over the plate of gap* **-** Figure 4 shows the computational model of coaches with flat plate. Here a flat palate is used to fill the inter car gap. The size of this plate is same as the size of the inter-car gap.

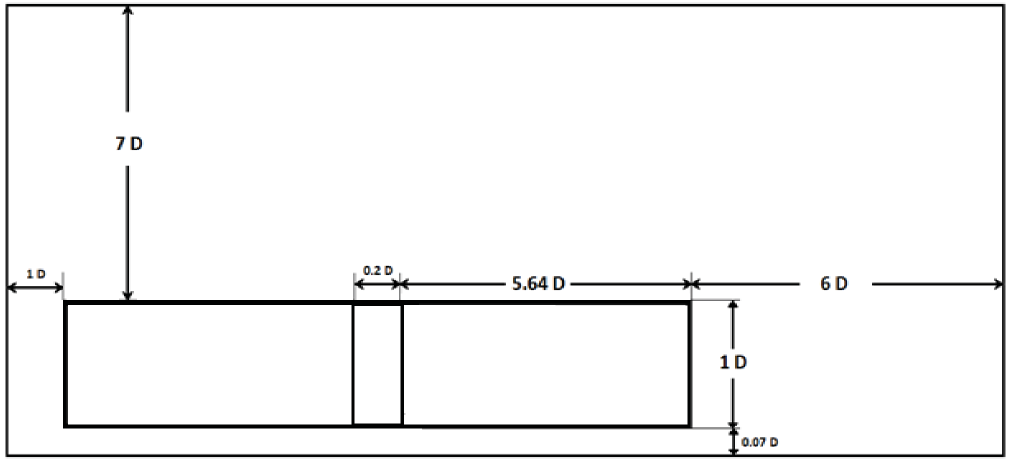

Figure 3: Computational model of coaches with flat plate

C. *Grid generation* - The generation of 2 - dimensional computational model and its meshing has been achieved by a pre-processor named GAMBIT 2.2.30. For both the cases of with and without flat plate, all the faces have been meshed with quad mesh. The domain is divided into number of areas so that each area can be meshed with quad mapping scheme. Fine grids are generated near the walls or where the flow dynamics is complex such as inter car gap where the vortex are generated. The fine grids are placed in such a manner so that the vortex generation in cavity wall y+<1 criterion can be fulfilled. Meshing in case of without cavity is fined near to the upper and lower walls of the coaches and plate.

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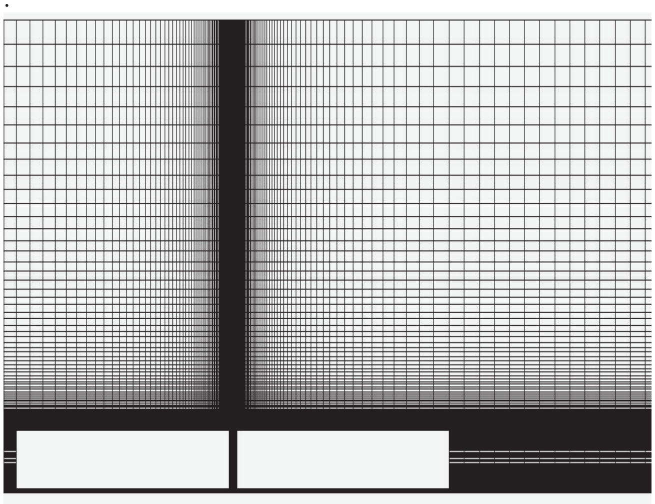

Figure 5: Grid view of full model

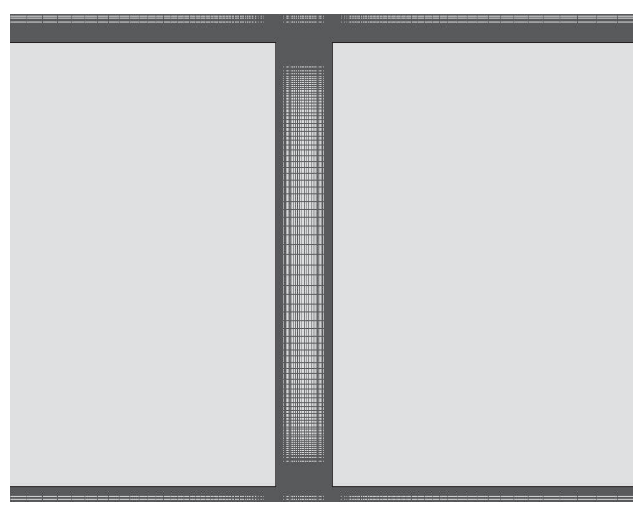

Figure 6: Grid view of inter-car gap area

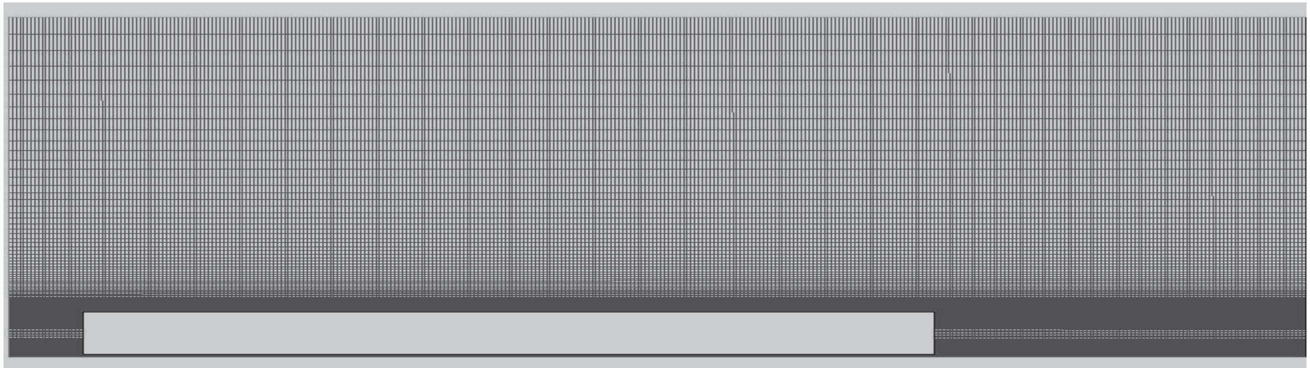

Figure 7: Grid view of model when gap is not available

D. *Governing Equations:* The equations used here are continuity, momentum. These equations can be expressed in the conservative form as,

Continuity equation: $\frac{\partial \rho}{\partial t} + \nabla . (\rho \vec{U}) = 0$

Momentum equation: $\frac{\partial (\rho \vec{U})}{\partial t} + \nabla . (\rho \vec{U} \vec{U}) = -\nabla p + \nabla \tau$

E. *Turbulence model:* The model used here is the k-ε standard turbulence model. (k-ε) turbulence model is the very common model used in Computational Fluid Dynamics (CFD) to analyze mean flow characteristics for turbulent flow conditions. It has two equation models which gives the description of turbulence by means of transport equations (PDEs).

The transportation equations for a standard k-ε turbulence model are as follows

Turbulent kinetic energy equation:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho k u_j) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + P_k + P_b - \rho \varepsilon - Y_M + S_k$$

Energy dissipation rate equation:

$$\frac{\partial}{\partial t}(\rho \varepsilon) + \frac{\partial}{\partial x_j}(\rho \varepsilon u_j) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \rho C_1 S \varepsilon - \rho C_2 \frac{\varepsilon^2}{k + \sqrt{\nu \varepsilon}} + C_{1\varepsilon}\frac{\varepsilon}{k} C_{3\varepsilon} P_b + S_\varepsilon$$

F. *Boundary condition:*. In order to have a good validation the different boundary conditions applied through FLUENT and are explained as follows:

1. *Velocity inlet* - Velocity inlet boundary condition has been applied at one at mainstream inlet. Velocity is specifying normal to boundary and magnitude and reference frame is absolute for this condition. Velocity magnitude at the inlet is 20 m/s. The initial gauge pressure is taken as constant because the train runs in ambient condition. Turbulence is specifying by its primary parameter, length scale and its intensity.

Turbulent intensity	= 0.1 %
Turbulent length scale	= 0.01 m

2. *Pressure Outlet* - Pressure outlet boundary condition is given at the boundary from where mass flux is coming out of the domain. Gauge pressure, turbulent intensity and length scale are set as zero, 300K, 0.1% and 0.01m.

3. *Symmetry wall* - The top and bottom wall has been given symmetric boundary condition. ANSYS Fluent assumes a zero flux of all quantities across a symmetry boundary. There is no convective flux across a symmetry plane: the fluid slips freely on this boundary, there is no boundary layer formation, the normal velocity component at the symmetry plane is zero and the normal gradients of all flow variables are zero at the symmetry plane.

4. *Wall* - All other walls (coach and plate) of the computational domain are given as wall boundary condition with no slip shear condition and without motion, zero heat flux and zero heat generation i.e., adiabatic

V. RESULTS

A. Case – 1: Analyses with inter car gap **-** The result of analysis with inter-car gap is shown below which carried the analysis of grids, flow of air in inter-car gap and discussion on aerodynamic drag on train.

1. *Flow structure analysis* **–** Figures 8 & 9 are of contours, stream line and velocity vectors are showing the behavior of flow. As it can be seen in the figure that the flow in cavity area is in the form of vortex. From the stream lines it can see near to the cavity and at the diffusion angle vortex are formed. These vortex are the main cause of reduction of power of locomotive.

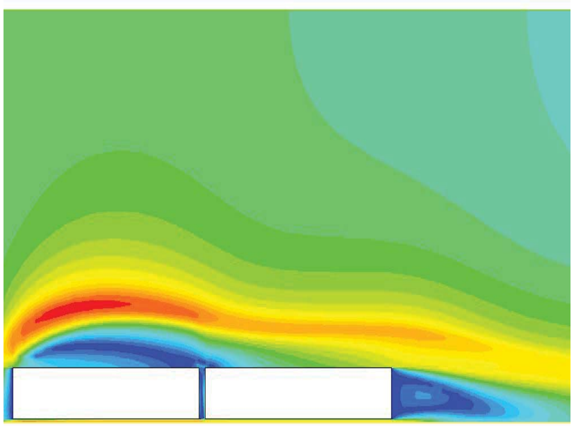

Figure 8: Contours of velocity magnitude when gap is available

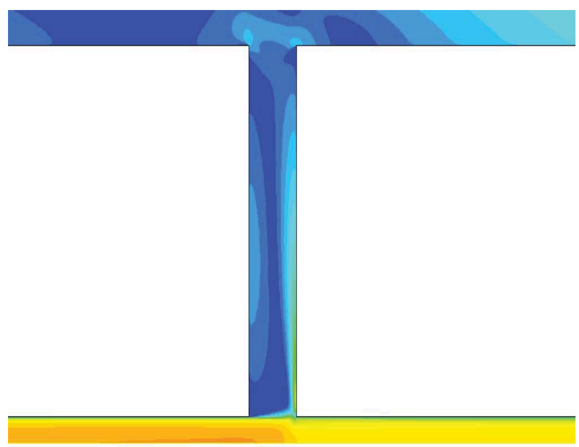

Figure 9: Contours of velocity magnitude in inter-car gap area

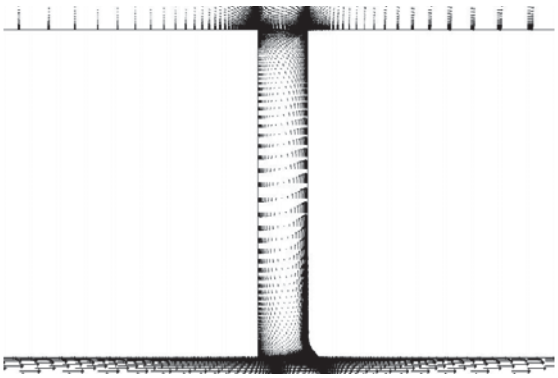

Figure 10: velocity vector in the inter-car gap

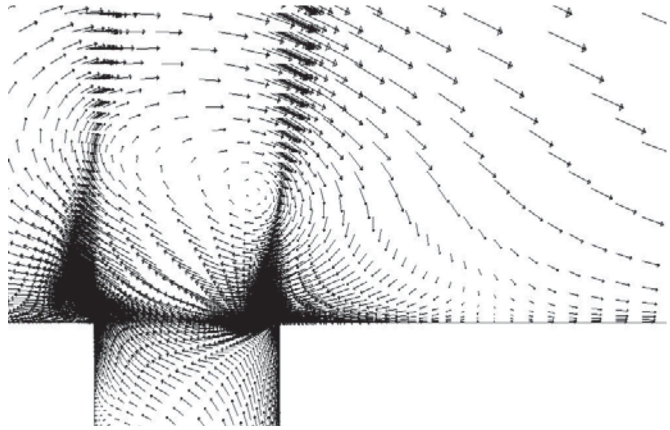

Figure 11: velocity vector near to upper wall of coaches

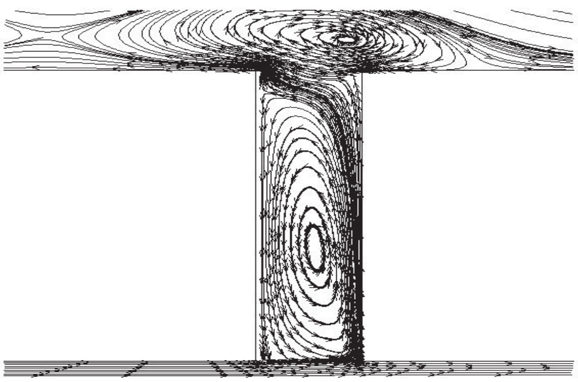

Figure 12: Flow of stream lines in the gap area

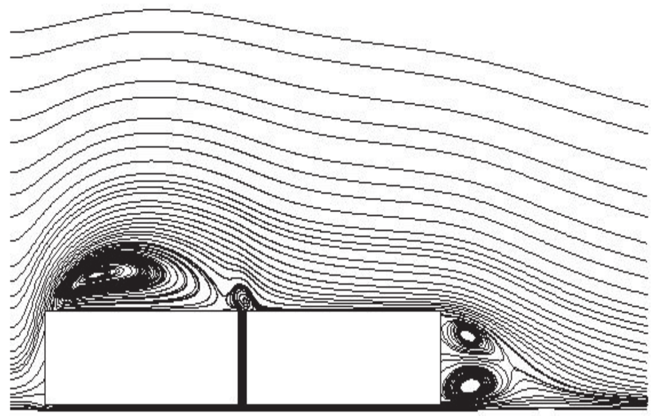

Figure 13: Stream lines in model with inter-car gap

B. Case -2: Analysis when train coaches are continue / without inter-car gap / by using the filler

a) Grids - The orthogonal quality range is same as the range of case-1 which is 0 to 1. The minimum orthogonal quality is 4.40351E+2 and the maximum aspect ratio is 4.40351E+2.

b) Flow structure analysis **–** Figures 13 & 14 are showing the flow behavior of air over the coach. After the analysis the flow over the continued train behaves as the flow over the flat plate. From the figure it can be seen that the vortex are generating over the upper wall or roof of the coach. This plate helps to reduce the aerodynamic drag over the inter-car gap of the train.

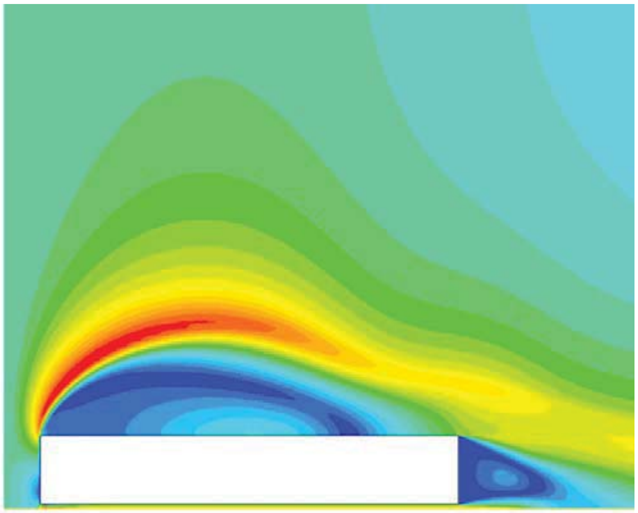

Figure 14: contours of velocity magnitude

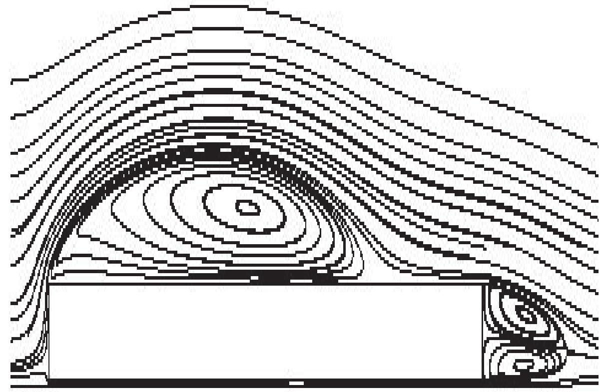

Figure 15: stream lines in the model

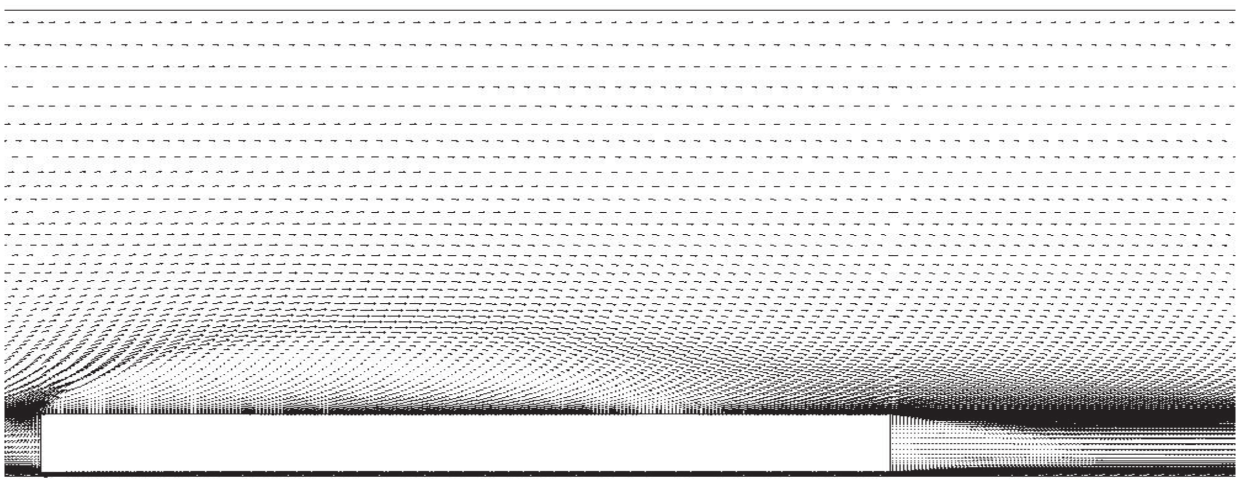

Figure 16: Velocity vector when gap is filled

VI.CONCLUSION

In the study, the aerodynamic drag reduces computationally in the inter-car gap of trains by using the flat plate over the portion of cavity. The size of inter-car gap in the train is 0.75 meter. The study is carried for the ambient condition in which the velocity of train is 20 m/s, due to which the Reynolds number increases, higher Reynolds number is responsible for the turbulence. This turbulence is defined by the k-ε standard turbulence model, for this model intensity and length scale has been discussed above.

A detailed flow has been presented with and without the gap in train. According to the results, in the gaped area the wake flow generates due to which vortex is formed, this can be reduced by filling the gap by some plate or by air bags. The result with continued train is good which shows the reduction of aerodynamic drag over the walls of train. Analysis and mathematical calculation shows that, by using the filler in the gap the aerodynamic loss reduces up to 3 - 4 % for a gap between two coaches. If a locomotive having 20 bogies moving with the higher speed for a long journey then the aerodynamic loss can be reduced on very big scale.

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