



Aerodynamic Control in High Speed Trains with a Novel Design of Wing Set

Mehmet ÇİÇEK^{1,*} , Gökhan DURMUŞ² 

¹Emek Mah. 2.Temel Sk. No 6 Hudeyfe Company, Antakya, Hatay, Turkey

²Faculty of Aeronautics and Astronautics, Anadolu University, Eskisehir, Turkey

ArticleInfo

Received:12/09/2018

Accepted:24/12/2018

Keywords

High-speed trains (HSTs),
Aerodynamic breaking,
Aerodynamic control,
Railway,
Derail,
Wing,
Centrifugal force

Abstract

Different from previous aerodynamic brake studies where aerodynamic brake is used to support conventional brakes, in this paper, a novel design of wing set for high speed trains (HSTs) has been proposed to provide safer and faster movement in curved rails. We have investigated, for the first time, the contribution of those two-axis wings on the running capability of a HST in a curved path to reduce derail or overturn risk. We have put 6 wings, 4 on sides which are proposed first time and 2 on top on each car. We have found that at same speed (0.8ma), minimum radius of curvature decreased from 7km to 3km when the wings are used. In the second part, the advantages of the aerodynamic drag brakes induced from proposed novel design wings at the speed of 0.8ma are discussed.

1. INTRODUCTION

In the 19th century the speed of the trains was about 100 km / h. It was utopia that the speed of the trains reached 250 km / h in those days. Newly, high-speed trains (HSTs) can get speeds of up to 400 km/h and test trains reaching 600 km/h have been produced [Zhang et al. 2018, Jianyong et al. 2013]. HSTs have become a popular and important transportation way due to its advantages of high speed and efficiency, which draws attention worldwide [Li et al. 2017]. As it will be appreciated, the increase in velocity increases the attention worldwide and importance of aerodynamic controlling of a HST.

In connection with the increasing speed, many engineering problems, which have been ignored at low speeds, come up [Vasovic et al. 2011]. When driving fast on a straight path, the vehicle should have a minimal aerodynamic drag, and the down force does not need to be large. When braking, the vehicle should have a significant aerodynamic drag and should produce a greater down force [Pietrzak P. and Piechna J., 2013]. The fast cornering and driving through curves requires great aerodynamic down force and the forces acting perpendicular to the wheels on both side must be close to each other. The actuatable aerodynamic parts (wings) attached to the vehicle body can be the solution that change the aerodynamic characteristics of the vehicle and minimize derail or overturn risk. Therefore, actuatable wings should be used not only in braking but also be used in such cases like secure fast cornering.

The force equivalent of the HST braking force is proportional to the square of the velocity. Thus, aerodynamic brake method is very effective at high speeds [Wu et al. 2011]. Unlike sliding frictional shoe brake and wheel disc brake, the aerodynamic brake is designed to produce negative force by increasing aerodynamic drag with wings or panels attached to the car body [Yoshimura et al. 2000]. In aerodynamic brake, wings block the air stream and a positive pressure occurs in front of it while negative pressure is formed behind it. The resulting pressure difference creates a resistance force normal to the surface of the panel and serves as a braking force. When a HST enters to a curved path, different magnitudes of forces

*Corresponding author, e-mail:elektrik.mehmetcicek@gmail.com

are applied to the left and right wheels. If there is a large difference between the magnitudes of forces, the HST may derail or overturn. But independent-controlled two axis-wings attached to the cars of a HST can be used to equalize the forces on wheels on both sides to ensure safer and faster travel.

In this study, I proposed a novel design of wing set attached to the cars of a HST and have investigated, for the first time, the effects of those two-axis wings on the running capability of a HST in a curved path to reduce derail or overturn risk. In the second part, the contributions of aerodynamic drag brakes induced from novel design wings are examined. It is assumed that the HST has five cars (Fig. 1).

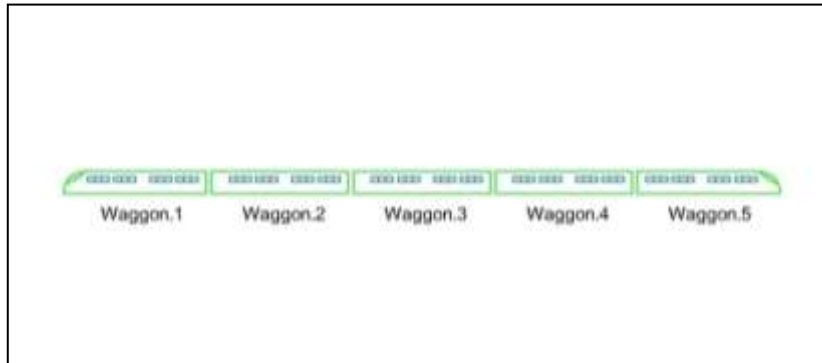


Figure 1. Schematic drawing of a high speed test train

Each car's length, width and height are 25m, 4m and 4m, respectively (Fig. 2). Each car has 6 unibody wings, two on top and four on sides which are reversely movable (Fig. 3).

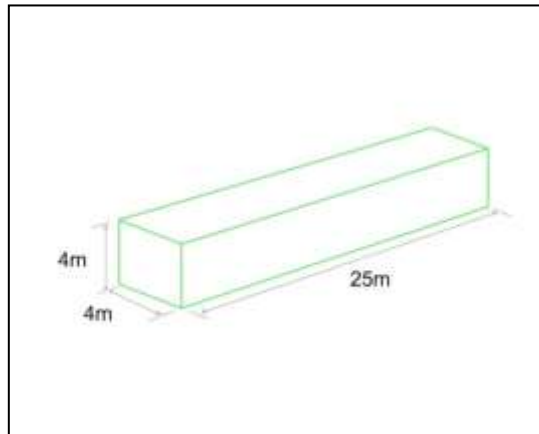


Figure 2. Assumed dimensions of each car

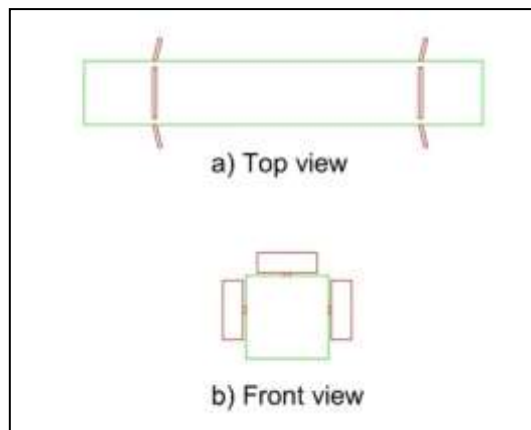


Figure 3. Placements of the wings on a single car

The train speed was considered as to be 0.8 ma. All wings are actuatable and can move independently in two dimensions around z and y axis (Fig. 4).

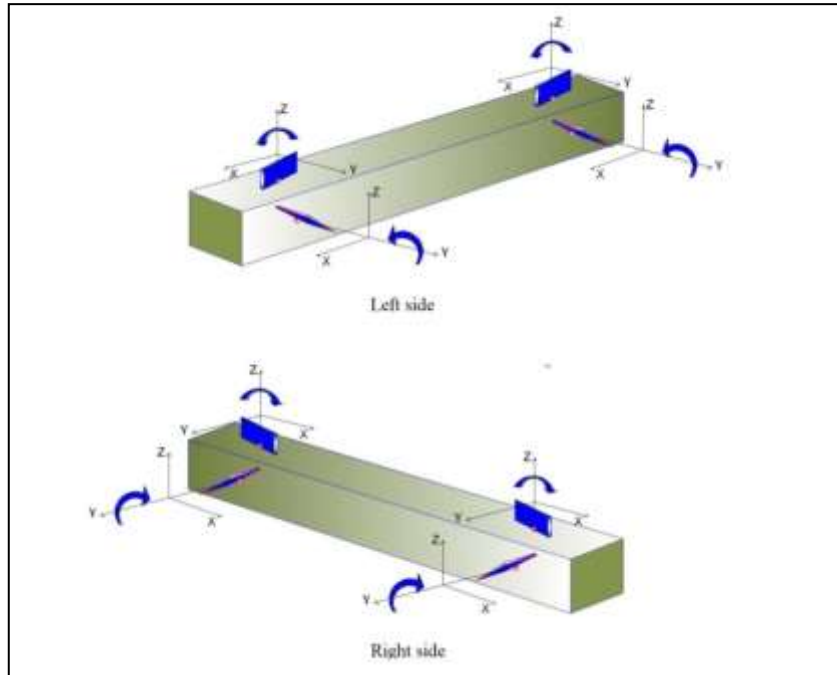


Figure 4. Actuable wings which can be controlled independently in two dimensions around z and y axis

They are normally closed when the train moves straight. The wings of course act as aerodynamic drag brake for slowing the vehicle in addition to conventional brake. But we primarily aim to use these two axis-wings for ensuring safer travel in curved paths by modifying the forces acting on P_1 and P_2 wheels (Fig. 5). When the angular positions of the wings are changed, forces on P_1 and P_2 can be tuned accordingly.

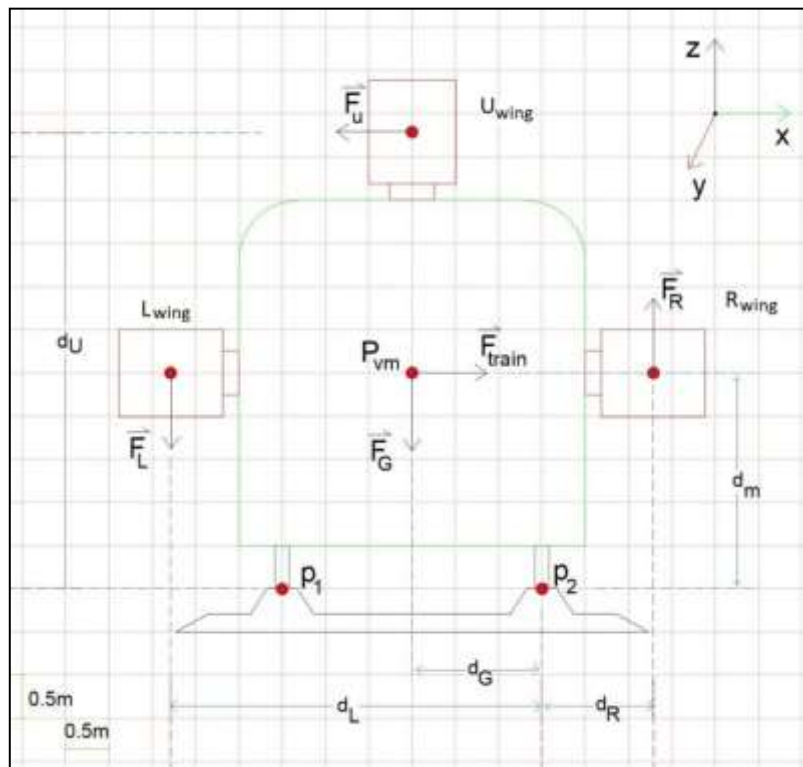


Figure 5. Front view of a car showing the forces acting on the wheels

2. MATERIALS AND METHODS

2.1. Aerodynamic Control

The magnitude of centrifugal force (F_{train}) and its moment according to the points P_1 and P_2 can be estimated by using the following equations, respectively [Halliday and Resnick, 1981];

$$F_{train} = mV^2/r \quad (1)$$

$$M_{train} = d_m F_{train} \quad (2)$$

where m is the mass of car, V is linear velocity, r is radius of curvature (Fig. 6) and d_m is the perpendicular distance of the force to the points P_1 or P_2 . The moment that the wings generate (M_{wing}) causes overturning moment of F_{train} to decrease. (Fig. 7).

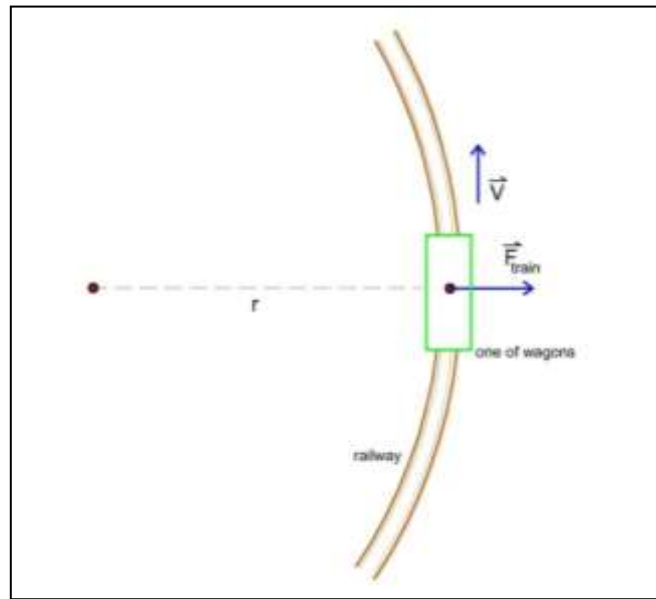


Figure 6. Schematic description of radius of curvature

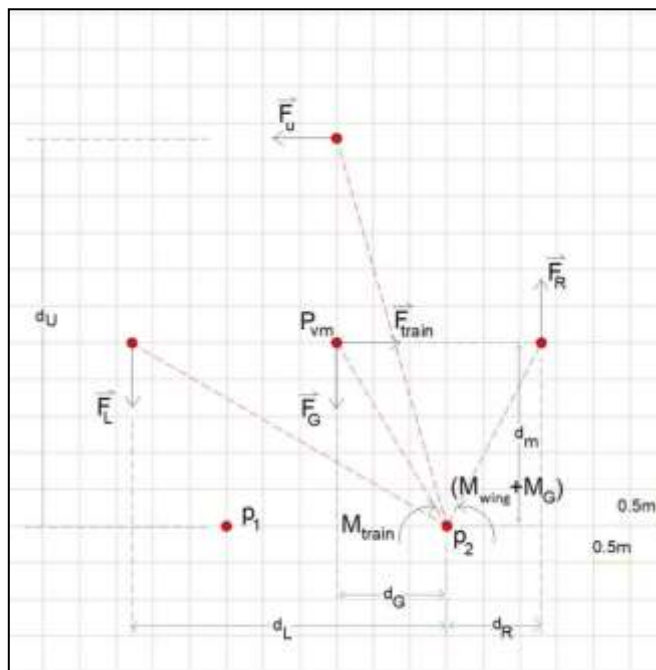


Figure 7. A schematic drawing showing the forces, their distances and their moments

The total moment and the forces caused by the upper, left and right wings for a single car can be estimated by performing the following calculations;

$$M_{total} = M_{train} + M_{wing} + M_G \quad (3)$$

$$M_{total} = d_m F_{train} + 2F_U d_U + 2F_R d_R + 2F_L d_L + d_G F_G \quad (4)$$

$$F_L = F_U = F_R = \frac{1}{2} \rho_0 V^2 S C_L \quad (5)$$

$$F_G = mg \quad (6)$$

where M_G is the moment of gravity of the car, ρ_0 is the density of air, S is surface area of each wing, C_L is the lift coefficient, g is the acceleration of gravity and F_U , F_R and F_L are the forces caused by upper, right and left wings, respectively. In Equation 5, the value of C_L will change according to the angel of wing. This work was considered as a wing NACA0012. The C_L value varies from 0.1 to 1.4. It was considered as 0.5 in the current study.

By performing a sample numerical analysis, we can see the effect of the wings. The preferred values for calculation are shown in Table 1.

Table 1. The preferred values for calculation of aerodynamic control

The values used in the calculation			
r (m)	d_U (m)	d_R (m)	d_L (m)
20000	5.3	1.3	4.3
d_m (m)	C_L	S (m ²)	m (kg)
2	0.5	3	60000
g (m/s ²)	ρ_0 (kg/m ³)	d_G (m)	V (ma)
9.8	1.225	1.5	0.8
Calculated values			
F_{train}	165.675 kN	M_U	537.8224 kNm
M_G	882.000 kNm	M_L	436.3465 kNm
$F_U = F_L = F_R$	50.7379 kN	M_R	131.9187 kNm
M_{train}	313.350 kNm	M_{flap}	1106.087 kNm

As can be seen from the Table 1, the moment caused by the wings is 3.5 times much larger than that of centrifugal force. It means that the train can safely run at a speed of 0.8ma on a curved rail with a radius of curvature of 20km.

In case in which the wings are closed, due to the mass of the train (Fig. 8), at the speed of 0.8 ma, the minimum radius of curvature of the rail required for the train to travel without overturning or derailling is 7 km. But, when the wings are used, the train can travel safely on a curved path with a radius of curvature of 3km if the weight of the train taken into account.

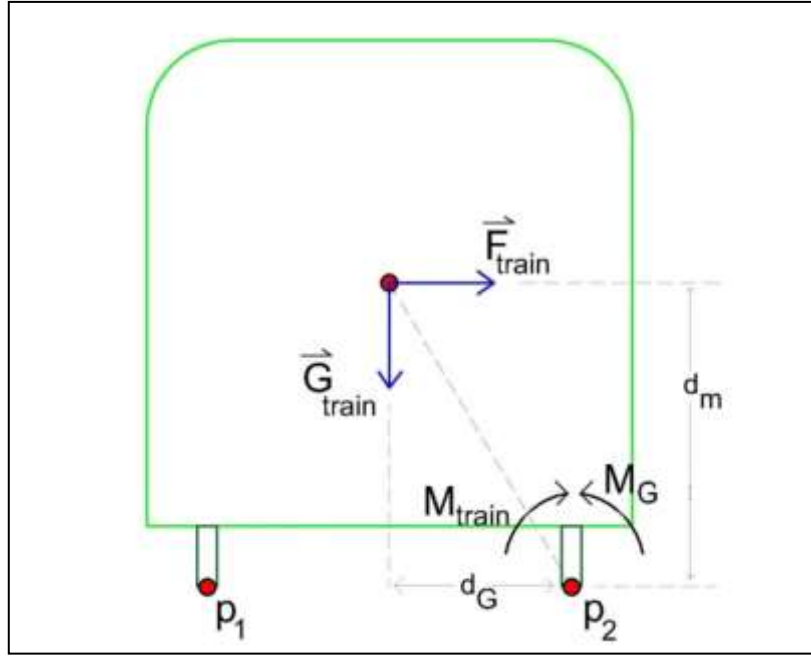


Figure 8. A schematic drawing showing the moments induced from the mass of train and the centrifugal force

1.2. Aerodynamic Braking

In HSTs, the braking systems can be classified as adhesion braking and non-adhesion braking. In adhesion braking, the maximum force between the wheel set and the rail limits the braking force while this limitation does not exist in non-adhesion braking [Sharma et al. 2015]. Therefore, non-adhesion braking techniques such as aerodynamic braking, eddy current braking and electromagnetic rail braking have great attention as techniques at high speeds to overcome the problem of effective braking [Vasovic et al. 2011; Jianyong et al. 2013]. Aerodynamic braking has several advantages over non-adhesion braking methods i) It stretches the brake panel to enhance aerodynamic resistance when braking. Since aerodynamic resistance is proportional to the square of the relative velocity, aerodynamic braking performs efficiently at high speed, and can be used to compensate for the deficiencies of adhesion braking. ii) Aerodynamic braking uses the relative speed between the natural wind and the vehicle. Unlike other braking methods, such as disc braking and electrical braking, aerodynamic braking has a relatively simple control scheme [Jianyong et al. 2013].

When the aerodynamic brake is in the extended position, it blocks the airflow and overpressure occurs in front of it, while behind it an area of negative pressure is formed due to the flow separation behind the plate. The difference in pressures between the front and the rear brake panel surface creates a resistance force normal to the surface of the panel and serves as a braking force. The tangential force induced by the surface friction is negligible when compared to the normal force [Vasovic et al. 2011].

In this section, the influence of the wings which are perpendicular to airflow is examined. All wings were taken into account to calculate total braking effect of them. The friction forces and viscous forces are neglected. A simple Matlab algorithm can be used to calculate the effect of wings. The following equations were used to calculate drag force, acceleration and final velocity, respectively. Table 2 shows the values chosen just for example and calculated quantities. Because drag coefficient (C_D) changes between 0.03 and 1.4, it has been taken as 0.5 that is an average value.

$$F_{drag} = \frac{1}{2}\rho_0 V^2 S C_D \quad (7)$$

$$a = F_{drag}/m \quad (8)$$

$$V_{final} = V_{initial} - at \quad (9)$$

Table 2. The values used in the calculation and the estimated final speed

$V_{initial}$ (km/h)	ρ_o (kg/m ³)	C_d -	m (kg)	S (m ²)	t (s)
1000	1.225	0.5	300000	90	90
Calculated final speed (km/h)					
$V_{final}=269$					

As can be seen from the Table 2, train speed decrease from 0.80ma to about 0.22ma after 90 seconds of aerodynamic braking without the help of any other braking system under our experimental conditions. When the train speed falls below 300 km/h, it can be switched to conventional braking. Aerodynamic braking and conventional braking can be used together in emergency situations.

3. CONCLUSION

Aerodynamic control in high-speed trains will be an important study area for the future. In this study, we proposed a novel design wing set attached to both side and top of the car for the first time. We investigated the advantages of the wings on reducing derail or overturn risk. It was found that minimum radius of curvature decreased from 7km to 3km with the usage of wings. With the support of the proposed wing set, it was estimated that, the train having the speed of 0.80ma decreased its speed to 0.22ma after 90 seconds of aerodynamic braking without the help of any other braking system. The results of the analysis showed that aerodynamic control has serious advantages.

- Reduces the risk of centrifugal force and derailment risk, ensuring that the train travels more safely,
- It can ensure that the train keeps its speed during cornering,
- It shortens the travel time,
- It extends the life of the wheel bandages.
- It extends the life of electric motors by reducing dynamic braking.
- It reduces the wear of the railway.

This work keeps a light on the work that will enable fast trains to travel at very high speeds. Patent assessment of this wing design proposed in the paper is pending.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors

REFERENCES

- Halliday, R., Resnick, R., 1981. Fundamentals of physics, 2nd edition, *John Wiley & Sons*, New Jersey.
- Jianyong, Z., Mengling, W., Chun, T., Ying, X., Zhuojun, L., Zhongkai, C., 2013. Aerodynamic braking device for high-speed trains: Design, simulation and experiment. *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit* 228: 260.
- Li, Z., Yang, M., Huang, S., Liang, X., 2017. A new method to measure the aerodynamic drag of high-speed trains passing through tunnels. *Journal of Wind Engineering & Industrial Aerodynamics* 171: 110–120.
- Pietrzak P., Piechna J., 2013. Numerical investigation of the controllable wing stall caused by the air injection, *The Archive of Mechanical Engineering*, LX(2): 199-216.

Sharma, R.C., Dhingra, M., Pathak, R.K., 2015. *Braking Systems in Railway Vehicles*. *International Journal of Engineering Research & Technology*, 4(1): 206-211.

Vasović, I., Maksimović, M., Puharić, M., Matić, D., Linić, S., 2011. *Structural Analysis of Aerodynamic Brakes in High-Speed*. *Trains Scientific Technical Review*, 61(2): 10-15.

Wu, M., Zhu, Y., Tian, C., Fei, W., 2011. Influence of aerodynamic braking on the pressure wave of a crossing high-speed train. *Journal of Zhejiang University-Science A (Appl Physics & Engineering)* 12(12):979-984.

Yoshimura, M., Saito, S., Hosaka, S., Tsunoda, H., 2000. Characteristics of the Aerodynamic Brake of the Vehicle on the Yamanashi Maglev Test Line. *Quarterly report of Railway Technical Research Institute*, 41(2): 74-78.

Zhang, J., Wang, J., Wang, Q., Xiong, X., Gao, G., 2018. A study of the influence of bogie cut outs' angles on the aerodynamic performance of a high-speed train. *Journal of Wind Engineering & Industrial Aerodynamics* 175: 153–168.