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EFFECTS OF CROSSWIND ON THE DRAG OF MEDIUM SPEED TRAINS

David Prayoga Paramaputera
Student
Atma Jaya Catholic University of Indonesia
Department of Mechanical Engineering
Email: d.prayoga.p@gmail.com

Sheila Tobing
Lecturer
Atma Jaya Catholic University of Indonesia
Department of Mechanical Engineering
Email: sheila.tobing@atmajaya.ac.id
Lecturer
Universitas Indonesia
Faculty of Engineering
Email: sheila.tobing@ui.ac.id

Matza Gusto Andika
Researcher
Badan Pengkajian dan Penerapan Teknologi
Balai Besar Teknologi Aerodinamika, Aeroelastika, dan Aeroakustika
Email: matza.gusto@bppt.go.id

Aerodynamic research on medium-speed trains is trying to map the flow of fluid around trains. The train model testing is conducted to study Cd values experimentally using a closed-loop wind tunnel at the Balai Besar Teknologi Aerodinamika, Aeroelastika, dan Aeroakustika. In addition to the experimental method, the computational method can be used to validate the experimental results, map the fluid flow around the train model, and calculate Cd values. The computational results of Cd obtained using ANSYS are compared against Cd values from wind tunnel tests. Further analysis using the ANSYS program with variations in the yaw angle can predict crosswind effects on the train model. It is found that vortices are formed around the train body, and modifying the head shape and adding fairing increases Cd values.

Keywords: *Wind Tunnel,* ANSYS*, Medium Speed Train, Finite Volume Method, Crosswind*

1. INTRODUCTION

The development of the medium speed train by PT INKA in collaboration with the Badan Pengkajian dan Penerapan Teknologi, Balai Besar Teknologi Aerodinamika, Aeroelastika, dan Aeroakustika (BPPT BBTA3), Puspitek Serpong requires several considerations before application in real life, including research on the aerodynamics experienced by the train body in its cruise speed and the phenomenon of crosswinds. For example, aircraft development requires a streamlined body design or current split. In contrast, land vehicles operating above ground require consideration of the length-to-diameter ratio, the effect of crosswinds, and body shape with optimal drag coefficient values before the production process is carried out [1].

In this research, the analysis is carried out to determine how the yaw angle affects the Cd value on the medium speed train model and how much drag occurs in the BPPT medium speed train model and one modified head train model with the addition of a fairing. The purpose of this research is to determine the impact of changes in yaw angle on drag on two train models, the BPPT medium speed train or Model 2, and the modified head train with the addition of a fairing. The results of this study can provide an understanding of the effects of the design of a medium-speed train has on drag. In addition, the results of this study can provide insight into the impact of adding a fairing to protect the bogie component and determine the impact of changes in the shape of the head of the train to drag coefficient (*Cd*). This research also studied the visualization of airflow contours due to the crosswind phenomenon that occurs at various yaw angles.

Drag is a force that works in the opposite direction to the motion of an object [2]. Two components that play a role in the formation of total drag are induced drag and parasitic drag. Induced drag is the drag force of an object that is formed due to lift. Induced drag can only arise from three-dimensional flow; therefore, only skin friction, waves, and pressure drag occur in the case of airfoils. Parasitic drag is generated by the shape of objects (form) and surface friction. Parasitic drag is divided into several types, namely skin frictions drag, wave drag, and pressure drag. Skin friction drag is caused by the viscous force on the surface of the object. Wave drag is caused by the compressive force on the object's surface due to supersonic flow or shock waves [3]. Pressure drag is caused by compressive force due to the formation of a boundary layer on the object's surface. When the boundary layer begins to thicken, or in exceptional cases, a boundary layer separation is formed, the pressure drag can increase [3].

A crosswind is a phenomenon where the wind blows against the direction of the train at a certain angle. Crosswind can also cause instability of the train model due to the aerodynamic force of the airflow acting on the surrounding surface of the train [4]. Crosswind is investigated by increasing the aerodynamic forces, which

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can affect the safety of train operation. As many as 29 accidents involving the crosswinds phenomenon have been recorded in Japan since 1872 [4]. The stability of the crosswind effect received much attention from researchers to prevent accidents. Railway infrastructure with embankments on the tracks and a high distance from the ground surface is prone to wind blowing.

On the other hand, the study of the aerodynamics of trains under the influence of the crosswind with the help of various types of numerical simulations and wind tunnels is equally essential. Previous researchers investigated the flow structure around a simplified ICE 2 carriage model for yaw angles 35^0 and 90^0 [4]. Others investigated the aerodynamic performance around a simplified high-speed train model using the LES method. He found that the flow separation appeared laterally at the tip near the nose of the carriage leading to the creation of two vortices starting from the nose of the carriage [5]. Gawthorpe (1994) studied the effect of yaw angle under 45° on a simplified train model, and the results of his research resulted in a mapping of airflow around the train body [6].

1.1 Nomenclature

Cd	Drag Coefficient
β	Yaw Angle
V_0	Velocity
CDb	Wind tunnel drag coefficient

2. METHODOLOGY

The validation method used is Computational Fluid Dynamics (CFD) simulation using ANSYS Fluent. The addition of a fairing to the train has the purpose of providing safety to the bogie. Besides, the addition of the fairing also functions to reduce form drag [7]. This chapter describes the test steps carried out for the validation case and the parameters used in this research (Figure 1).

3. EXPERIMENTAL DATA

Through the tests carried out, it can be seen that the *Cd* values of the Head 2 model are smaller than the *Cd* values of the Head 1 model through a comparison of the *Cd* value at each yaw angle (Table 1 and Table 2). This high Cd of the Head 1 model can be caused by a less aerodynamic design or the addition of a cowcatcher to the Head 1 model, thus increasing the *Cd* value [8]. The flat front glass design on the Head 1 model can also add to the drag value because the shape is not aerodynamic. However, there is an advantage that the flat shape of the Head 1 carriage glass design does not cause visual distortion as produced in the curved glass on the Head 2 model, as shown in Figure 2.

Table 1: Aerodynamic forces of the Head 1 model measured in the wind tunnel.

V_0	*Yaw Angle* (β)	***CDb*** **of Head 1**
44.22	-44.99	1.0266
44.1	-29.99	1.6244
44.03	-20.03	1.5408
44.01	-9.93	1.3733
44.03	-0.01	0.9904
44.05	9.99	1.323
44.06	20.07	1.533
44.07	29.97	1.5595
44.18	44.97	1.086

Table 2: Aerodynamic forces of the Head 2 model measured in the wind tunnel.

V_0	*Yaw Angle* (β)	***CDb*** **of Head 2**
44.06	-44.99	0.7142
44.07	-30.01	1.3123
44.05	-20.01	1.3516
44.03	-9.93	1.2085
44.03	0.01	0.84
44	9.99	1.1651
44.1	20.03	1.3547
44	29.98	1.2734
43.99	45.01	0.7646

4. COMPUTING METHODS (CFD)

The CFD analysis is carried out on the experimental model Head 2 and a modified model of the Head 2 with modifications in a fairing and a change in the head shape, as shown in Table 3 and Table 4. The setup and error targets of the validation cases are shown in Table 5.

Table 3: Comparison between two models.

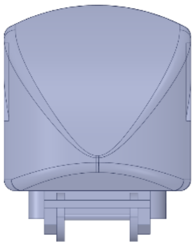
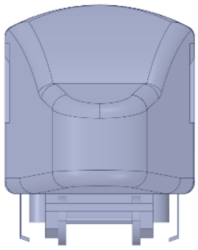
NO.	TRAIN DESIGN	MODEL NAME
1		Base model (Head 2)
2		The model with Fairing and Head Modification (Modified Head 2)

Table 4: Comparison between two models.

NO.	TRAIN DESIGN	MODEL NAME
1		Head 2
2		Modified Head 2

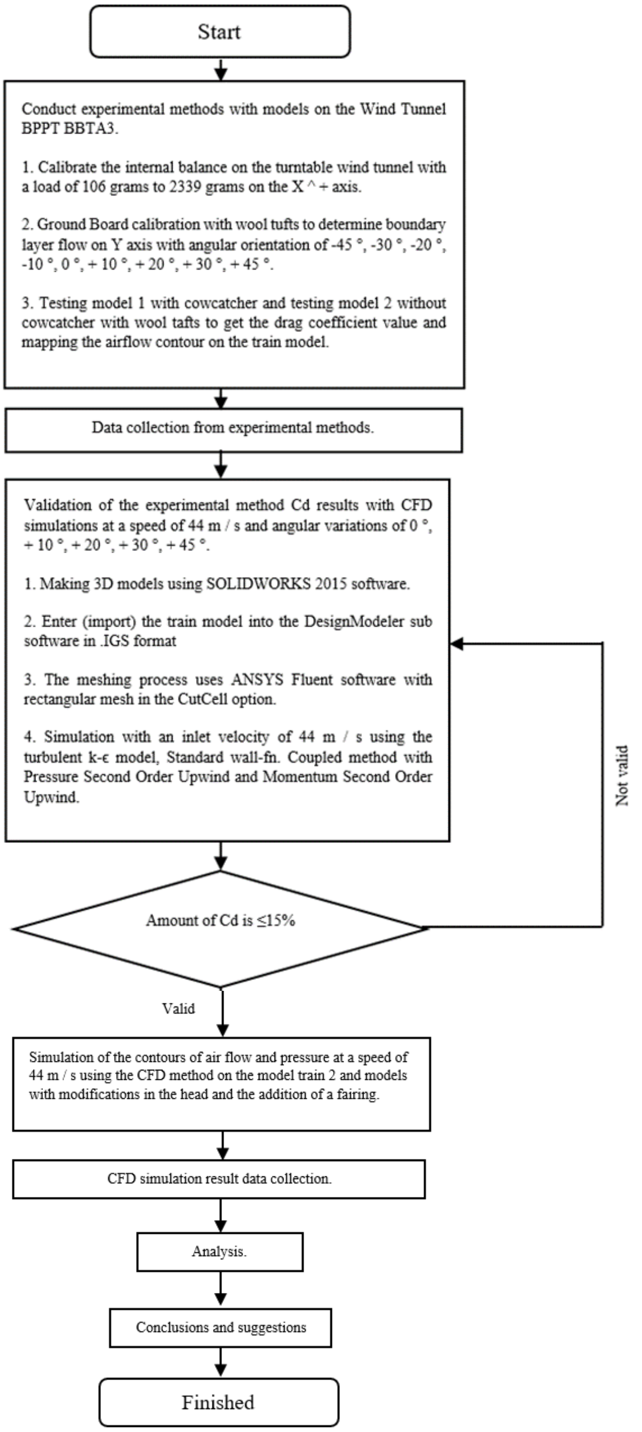


Figure 1: Methodology flow chart.

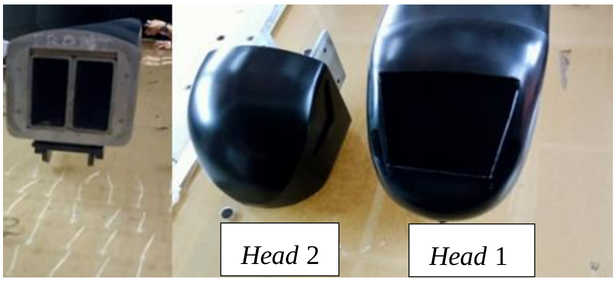


Figure 2: Head comparison of the two experimental models.

Table 5: The setup and error target of the validation cases.

FIXED VARIABLES	INDEPENDENT VARIABLES	INDEPENDENT VARIABLES VALUE	MODEL NAME	VALIDATION METHOD	OBJECTIVE
Velocity: 44 m/s	Angles	0°; +10°; +20°; +30°; +45°;	Head 2	Comparison with the experimental method	Error Value ≤15%

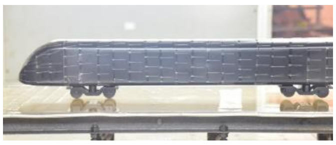
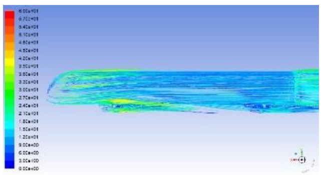
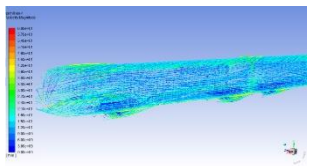
5. RESULT AND DISCUSSION

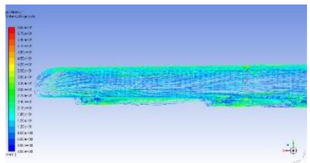
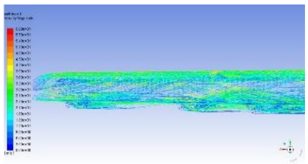
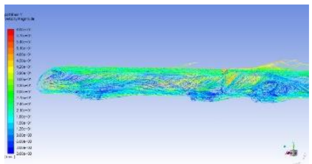
5.1 Case Study

This case study investigates the crosswind effects on the *Cd* of the train models. The train model is made based on technical drawings, and a predetermined scale is tested in the wind tunnel. The wind speed is kept constant at a speed of 44 m/s or equivalent to Re = 8,478,651.685 and with variations in the yaw angle of −45 °, −30 °, −20 °, −10 °, 0 °, + 10 °, + 20 °, + 30 °, + 45 °. Dimensional analysis has been fulfilled by comparing the two models using the same Reynolds number, namely 8,478,651.685 at a speed of 44 m/s and the dimensions of the train model in the wind tunnel and the train model in the ANSYS CFD are the same.

The air velocity contours in the experimental tests are depicted through the laying of wool tufts which function to see the airflow around the model train. During the simulation, the same thing can be done but using pathlines [9]. The airflow pathlines that exist at various angles show the same results as wool tufts in the experiments, and this is shown by several comparative figures such as at the yaw angle of 20°, where the flow that occurs around the joints between the carriages has the same pattern as presented in Table 6.

Table 6: Comparison between the flow patterns observed in experiments and simulations.

ANGLE	EXPERIMENTAL	SIMULATION
0°		
10°		

20°		
30°		
45°		

5.2 Validation of Model 2

The differences between the simulation and the wind tunnel results of the Head 2 model show that the maximum error value is below 10%. Through the comparison of *Cd* values, it can be seen that the *Cd* value is not constant even though it is at the same yaw angle (Table 7) [10]. For example, at an angle of -10° and +10°, a difference in *Cd* values of 1.2068 and 1.1644, respectively, is observed. This can be caused by the airflow velocity that is not constant in value, namely 44 m/s, as shown in the airflow velocity data (V_0).

Table 7: Cd data comparison of experiment results and simulation results for Model 2.

WIND TUNNEL MODEL HEAD 2				MODEL HEAD 2 ANSYS SIMULATION		
NO.	**β**	V_0	***Cd***	V_0	***Cd***	**Error**
1	-45	44.05	0.7005	44	0.72	2.70833 %
2	-30	43.99	1.3128	44	1.302	0.82949 %
3	-20	44.03	1.3437	44	1.321	1.71840 %
4	-10	44.06	1.2068	44	1.202	0.39933 %
5	0	44.01	0.8313	44	0.761	9.23784 %
6	10	44.03	1.1644	44	1.202	3.12812 %
7	20	44	1.3468	44	1.321	1.95307 %
8	30	44	1.2685	44	1.302	2.57296 %
9	45	44.07	0.7664	44	0.72	6.44444 %

The impact of the change in yaw angle or the orientation of the wind is the emergence of vortices and wakes from the flow around the train [11]. At a change in the angle from 0° to 10° (Figure 3), it can be seen that an increase in the total Cd value is a result of a significant increase in viscous / friction drag. The increase in total *Cd* from an angle of 10 ° to 20 ° is due to increased pressure drag [12]. From an angle of 20° to 30°, there is a slight decrease in total *Cd* due to a combination of reduced pressure and viscous drag. However, from 30° to 45°, there is a decrease in Cd due to a significant drop in viscous / skin friction drag.

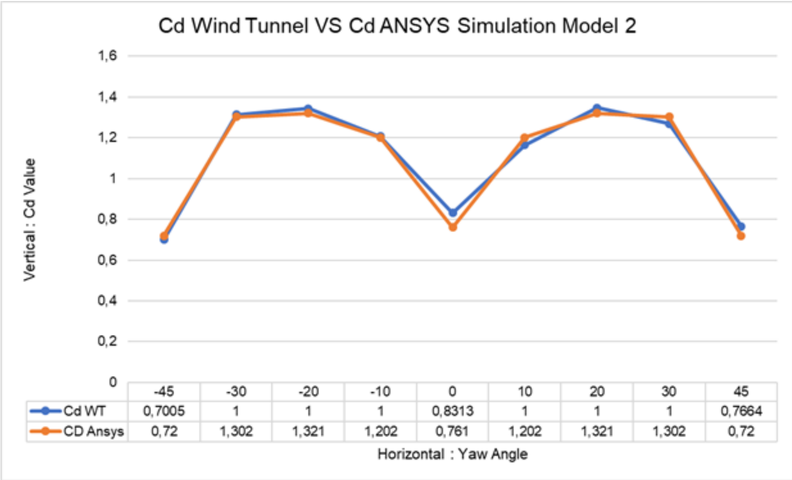


Figure 3: Cd value comparison between the wind tunnel tests and simulations of Model 2.

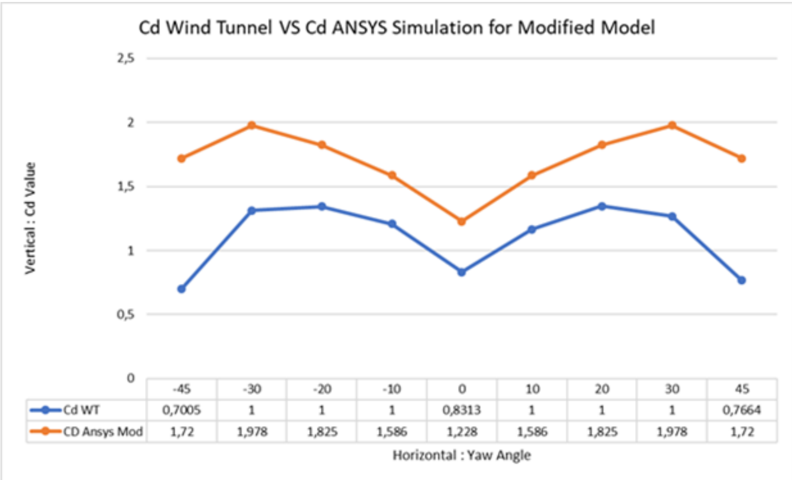


Figure 4: Cd value comparison between the wind tunnel tests of the Head 2 model and the simulation results of the Modified Head 2 model.

Table 8: Cd data of the wind tunnel tests of the Head 2 model and the simulation results of the Modified Head 2 model.

	HEAD 2 WIND TUNNEL			MODIFIED HEAD 2 ANSYS SIMULATION		
Num.	***β***	***V_0***	***Cd***	***V_0***	***Cd***	***Cd* INCREASE PERCENTAGE**
1	-45	44.05	0.7005	44	1.72	59.27326 %
2	-30	43.99	1.3128	44	1.978	33.62993 %
3	-20	44.03	1.3437	44	1.825	26.3726 %
4	-10	44.06	1.2068	44	1.586	23.90921 %
5	0	44.01	0.8313	44	1.228	32.30456 %
6	10	44.03	1.1644	44	1.586	26.5826 %
7	20	44	1.3468	44	1.825	26.20274 %
8	30	44	1.2685	44	1.978	35.86957 %
9	45	44.07	0.7664	44	1.72	55.44186 %

Figure 4 shows the simulation results for the Modified Head 2 with the addition of a fairing and the change in the shape of the train head to the Head 2 model. The increase in the values of *Cd* due to these modifications is caused by form drag which results in an increase and decrease in the curve [13]. The percentage difference in the value of *Cd* of the Modified Head 2 to the basic model or the Head 2 model also increases due to form drag [14]. Table 8 shows the *Cd* values of the wind tunnel test of the Head 2 and the simulation data of the Modified Head 2 model, and it can be seen that the impact of the head change and the addition of the fairing cause a significant change in the *Cd* values.

Table 9: Table of Pressure Drag Coefficient, Viscous Drag Coefficient, and Total Drag Coefficient.

MODEL HEAD 2				
NO.	ANGLE	PRESSURE	VISCOUS	TOTAL DRAG COEFFICIENT
1	0^o	0.5839	0.1771	0.761
2	10^o	0.677	0.525	1.202
3	20^o	0.823	0.498	1.321
4	30^o	0.712	0.59	1.302
5	45^o	0.6242	0.0958	0.72

The changes in yaw angle or the orientation of the wind cause different vortices and wakes to appear around the train. At a change in the angle of 0 ° to 10 ° showed in Table 9, it can be seen that an increase in the total *Cd* value is a result of a significant increase in viscous / friction drag [15]. The increase in total *Cd* from an angle of 10° to 20° is due to increased pressure drag. From an angle of 20° to 30°, there is a slight decrease in total *Cd* due to a combination of reduced pressure and increased viscous drag. From 30° to 45°, there is a fall in *Cd* due to a significant decrease in viscous / skin friction drag.

6. CONCLUSION

Based on the research and testing that are carried out both in wind tunnels and through CFD simulations, several conclusions are withdrawn, including:

1. Drag generally increases from a yaw angle of 0° to 30°. Drag force is dominated by pressure drag.
2. Drag decreases from an angle of 30° to 45°. The decrease in drag is caused by a significant decrease in viscous / skin friction drag.
3. The medium-speed train model that experiences the least drag is the BPPT Head 2 model.

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