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Surface Pressure Characteristics over Indian Train Engine

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In the present study, the surface pressure distribution of Indian train engine was experimentally investigated. A scaled model of the engine was tested at different Reynolds numbers ranging from 3.22×10^4 to 14.49×10^4. The aerodynamic drag and the variation of the pressure drag with Reynolds number are studied. The results show that the pressure distribution is not affected significantly with Reynolds number and the maximum coefficient of drag of 0.6005 is obtained at Reynolds number 6.44×10^4. The mean drag was also calculated for further understanding of drag characteristic of the engine model.

***Keywords*:** Surface pressure characteristics, Indian train, Drag characteristics

1. Introduction

Trains are the most preferred mode of transport in India ferrying about 23.07 million passengers per day with around 12617 trains per day [1]. This accounts for around 2% of the total population taking the train every day to commute. Improved railway network and accessibility have increased the patronage for trains over the years. To accommodate the surge in rail passengers, it is therefore deemed necessary to increase railway services to meet the demand. This, in turn, increases the energy demand for railways for traction of these trains. Hence, it is of prime importance to reduce energy demands to avert the energy crisis prevalent in developing countries. The drag force experienced by a train significantly contributes to its total energy expenditure. With the increase in speed of High-Speed Trains, the aerodynamic drag force increases thus leading to higher energy consumption [2]. Drag reduction of heavy vehicles is an important area of research as it varies monotonically with the fuel consumption of the vehicle [3]. The effect of the Reynolds number on the aerodynamic force and pressure of trains were investigated experimentally and was it was found that there was a significant effect on the pressure coefficient [4]. An experimental study investigated the influence of the frontal shape of a train and realized that a drag reduction up to 50% by altering its shape [5]. The unsteady aerodynamics of High-speed train has been an area of interest for a long time now. Experiments have confirmed that small-scale experiment techniques provided reliable drag characteristics of high-speed trains [6].

India is projected to have the largest railway network, but studies on the Indian trains are found to be limited. With extensive efforts being taken to reduce the travel time of trains by increasing the speed of the train, it is of utmost importance to study the aerodynamic characteristics of Indian trains to put forth possible design modification for an energy efficient train. The careful optimization of the nose and tail design can possibly reduce the intensity of the effect of the pressure drag [7]. The aim of this research is to study the surface pressure distribution of the Indian train engine and its aerodynamic drag.

2. Experimental Methodology

2. 1. Wind Tunnel

The experimental investigation was carried out in a Low-speed subsonic wind tunnel (Fig 1) at the Aerodynamics Laboratory of SASTRA Deemed University. The cross-section of the open circuit suction type wind tunnel is 300 x 300 mm and spans a length of 1500 mm. The flow speed of the tunnel can vary up to a maximum of 60 m/s and the freestream turbulence intensity is 0.51%.

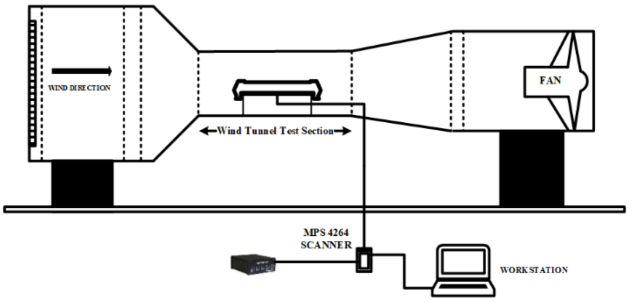

Fig. 1. Low-speed subsonic wind tunnel

2. 2. Model and Instrument

WAP 7 engine was the chosen model for the tests. The schematic diagram of the model is shown in the Fig. 2. A 1:60 scale model was designed and was fabricated by 3-D printing using Polylactic Acid with a resolution of 100 microns. A total of 42 pressure ports were made on the test model out of which only 15 were utilized for the current test. Since the test focuses on measuring the pressure drag, 12 of the pressure ports were arranged on the front and rear part of the model each at a distance of 1 cm from the previous one as shown in Fig. 2. The pressure ports were pneumatically connected to a simultaneous pressure scanner to obtain the surface pressure over the test model.

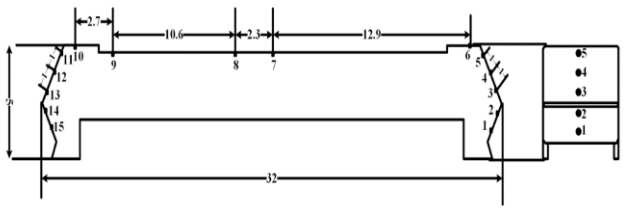

Fig. 2. The engine model and the location of pressure ports
(distance between ports in cm)

The model was mounted in the test section of the wind tunnel by a clamp in such a way that it does not hinder air flow. A 64-channel miniature ethernet pressure scanner (MPS 4264) (Fig. 1) of Scanivalve make was used to obtain the simultaneous surface pressure measurements of the model. The sampling frequency had been set at 700 Hz. The number of pressure data collected at each channel was 10,000.

2. 3. Calculation

The pressure distribution over the test model is understood by calculating the corresponding values of the coefficient of pressure at each pressure port which is calculated as given in equation (1). Drag over the test model is calculated in terms of coefficient of drag as given in equation (2).

$$C_p = \frac{P_i - P_\infty}{0.5\rho v^2} \tag{1}$$

$$C_d = \sum_{i=1}^{n} C_{pi} . s_i . cos\theta_i \quad (2)$$

where 'C_p' is the coefficient of pressure, 'v' is the freestream velocity, 'C_d' is the drag coefficient, 'S_i' is the distance between two pressure ports. 'θ_i' is the angle of the ports. 'ρ' is the density of freestream air. (P_i - P_∞) is the pressure difference measured by the pressure scanner. The Reynolds number is calculated by considering the height of the model as the characteristic length.

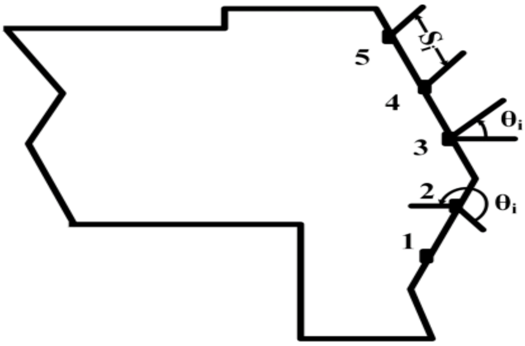

Fig. 3. Schematic representation of pressure ports

3. Results and Discussion

3. 1. Pressure distribution

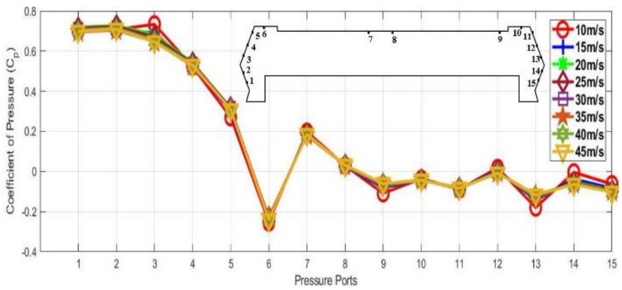

Fig 4. Surface pressure distribution of the WAP-7 engine model

The surface pressure distribution of the WAP-7 test engine model at different Reynolds number is as shown in Fig. 4. The pressure distribution in the front part of the model (port numbers 1- 5) is seen to show relatively higher-pressure loading with pressure coefficients (C_p) in the range of 0.2 – 0.8. This range of pressure coefficients was higher than that observed at the rear part of the model. This effect is due to the fact that the frontal region slows down the incoming flow, resulting in a high-pressure region [8].

A sharp change in the value of pressure coefficient is observed from port 5 to port 6 where pressure coefficient drops from C_p=0.3075 to C_p=-0.2423. Pressure port 6 exhibits the highest negative pressure coefficient that is attributed to the sharp change in the geometry at the top of the frontal part of the test model. A sharp change in the geometry leads to a sudden drop in the value of pressure coefficient [3] and this drop is due to flow separation [9]. Hence the change in geometry in the frontal region of the engine results in the onset of an adverse pressure gradient causing the flow to separate.

The trend observed in C_p plot after the pressure port 6 is possibly due to the flow reattachment on the flat upper surface of the test model. As a result, the pressure at ports 7 and 8 gradually approaches the ambient free stream pressure. A step like geometry on the rear side of the upper surface is responsible for the significant surge in pressure observed at port 9.

The ports 11- 15 are present on the rear side of the train model. The lower pressure on the rear side is indicative of a wake region. The pressure coefficients observed at the rear part of the train shows that flow again separates in close proximity to the port 13[9]. C_p in the rear part is found to be in the range of [-0.0836, -0.133]. On observation of the C_p distribution on the front and the rear part of the model, it is understood that there is an overall pressure difference between them. The differential pressure between the front and rear part of the model is responsible for the development of pressure drag on the model.

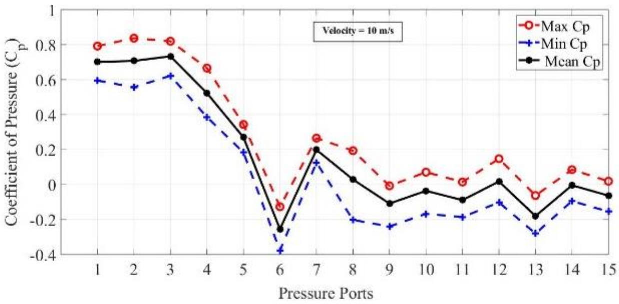

Fig. 5 Maximum, Minimum and Mean Pressure Coefficient across the length of the model at Re=6.44×10^4

The pressure distribution of 15 ports at a velocity of 25 m/s along with the maximum and minimum pressure coefficient values (Max C_p and Min C_p) is as shown in Fig. 5. The figure conveys that there has not been any abrupt fluctuation in the C_p values encountered during the experiment.

3. 2. Drag coefficient

The present study is limited to aerodynamic characteristics that arise due to pressure distribution over the engine. The pressure drag is the most dominant of the total drag observed for a bluff body [10]. Fig. 6 shows the variation of drag coefficient as a function of Reynolds number. From the figure, it can be inferred that there is no significant change in the coefficient of drag (C_d) with the increase in the Reynolds number. Over the entire Reynolds number range (Re) examined, the mean drag over the ranges of Reynolds number was found out to be 0.5897. Initially, the WAP- 7 test engine configuration had a drag coefficient of 0.5832 at a Reynolds number of 3.22×10^4 and 0.5882 at Reynolds number of 4.83×10^4. At Reynolds number (Re) = 6.44×10^4, the drag coefficient reaches the maximum value of C_d=0.6005 which is nearly 1.83% greater than the mean. Following that, the drag coefficient starts reducing till Re =11.27×10^4. At 12.88×10^4, the drag coefficient (C_d) undergoes a small increase and then settles down invariably. The drag coefficient (C_d) was found to vary negligibly in the range of Reynolds number 11.27×10^4 to 14.49×10^4. From these results, it has been identified that the variation of drag coefficient (C_d) with respect to Reynolds number (Re) is almost consistent with a maximum deviation of 1.83 % from the mean drag obtained at Reynolds Number =6.44×10^4.

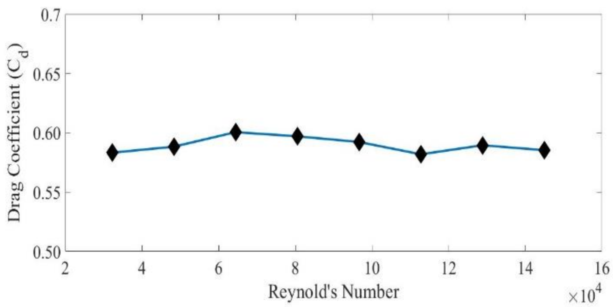

Fig. 6 Variation of C_d with respect to Reynolds number

The cause of the independence of Drag Coefficient with Reynolds number has to be analyzed by further investigation of the flow over the test model.

4. Conclusion

Experimental wind tunnel tests were conducted on a model of an Indian railway engine of WAP-7 type. The primary objective of this experimental investigation was to analyze surface pressure distribution and drag characteristics of the Indian train engine. The following conclusions are arrived at from the series of tests performed at 8 different Reynolds number ranging from 3.22×10^4 to 14.49×10^4.

1. The surface pressure distribution on the test model of WAP 7 engine is found to have minimal variations with change in Reynolds number.
2. The highest value of the coefficient of pressure drag is $C_d = 0.6005$ which is observed at an air velocity of 20 m/s (Re= 6.44×10^4).
3. The overall variation of pressure drag with respect to Reynolds number is found to be minimal. The maximum deviation of 1.83% from the mean pressure drag is reported at a velocity of 20 m/s (Re= 6.44×10^4).
4. The mean drag coefficient is observed to be $C_d = 0.5818$ over the range of Reynolds numbers in which the experiment had been conducted.

The underlying flow phenomenon is to be further examined to arrive at a comprehensive understanding of the drag mechanism. The C_d could be further reduced by altering the geometry of the model. The future of the study of aerodynamic characteristics of Indian train lies in the shape optimization of the nose of the train engine.

Acknowledgements

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