

EXPERIMENTAL ACTIVE FLOW CONTROL ON AHMED MODEL FOR AUTOMOTIVE AERODYNAMICS

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ABSTRACT

This study investigates influence of active flow control mechanism which is steady blowing that often aimed to reducing aerodynamic drag on the generic Ahmed model. Current experiments were conducted in a low-speed wind tunnel at a constant speed of 20 m/s, across yaw angles of -25° , -20° , -15° , 0° , 15° , 20° , and 25° . The application of active flow control reduced the drag coefficient (CD) by up to 18.6% at 0° yaw and by 12–15% across other yaw angles compared to the baseline model. Studies often show drag reduction impact by steady blowing but there is limited study on impacts at varying yaw angle of the model itself. Current study aimed to display influence of yawing to the aerodynamic force coefficients and pressure coefficients (C_p) of Ahmed model with 25° slant angle under effect of steady blowing. Since aerodynamic drag contributes approximately 75–80% of the total resistance of road vehicle at highway speeds, these results suggest strong potential for improving fuel efficiency and reducing emissions. Overall, the proposed active flow control design aligns well with existing experimental benchmarks and demonstrates effective drag reduction across all tested configurations.

KEYWORD

Wind tunnel, slant angle, aerodynamic characteristics, vehicle aerodynamics

INTRODUCTION

Several researchers have evaluated the effectiveness of steady and unsteady blowing. Phan et al. (2023) showed that a steady blowing jet on a square-back Ahmed body reduced aerodynamic drag by up to 26.5%, while unsteady jets achieved around 17.3%. Zhang et al. (2018) reported drag reductions of up to 29% on a 25° slant Ahmed body using multiple steady blowing slots. In contrast, unsteady jet actuation, while less effective in terms of absolute drag reduction, offers greater energy efficiency. Wang et al. (2019) obtained 13.6% drag reduction using a novel unsteady jet on a 25° model, while Phan et al. (2023) observed 17.3% reduction at 272 Hz.

Overall, the literature shows that steady blowing is most effective for achieving maximum drag reduction, while unsteady jets are more attractive for practical applications due to lower power requirements and higher energy efficiency. Plasma actuators offer additional potential but are currently limited by their power output. Despite extensive work on active flow control of Ahmed bodies, the combined influence of yaw angle and slant angle on aerodynamics, particularly with blower-based actuation, remains inadequately addressed. This study aims to fill this gap by experimentally and numerically investigating the aerodynamic behaviour of an Ahmed model under various yaw and slant angles, with active control devices. The specific objectives include evaluating pressure distribution, aerodynamics forces, and the influence of blower location on aerodynamic performance.

METHODOLOGY

The main research employs Ahmed model with 15° , 25° , 45° and 90° slant angle as shown in Figure 1 and Figure 2. However, only model with 25° slant angle will be discussed in this paper. This model is comprised of two parts that are detachable which is the front section (constant shape) and rear section (varying slant angles). This is done so to rapidly change the 4 slant angles for various experiments comparisons of the main research. There are 10 steady blowing locations holes located on top of front section and pressure taps along the centreline as indicated in Figure

1. The experimentation of this generic road vehicle model was executed using open-loop wind tunnel of UTM Aerolab. The test section of this open-loop wind tunnel has dimensions of 1.27 m long, 0.457 m wide, and 0.457 m tall. Meanwhile the Ahmed model used has dimensions of 0.35 m long, 0.13 m wide, and 0.12 m tall.



Figure 1: The Ahmed model inside the wind tunnel test section with 90° slant angle rear section.

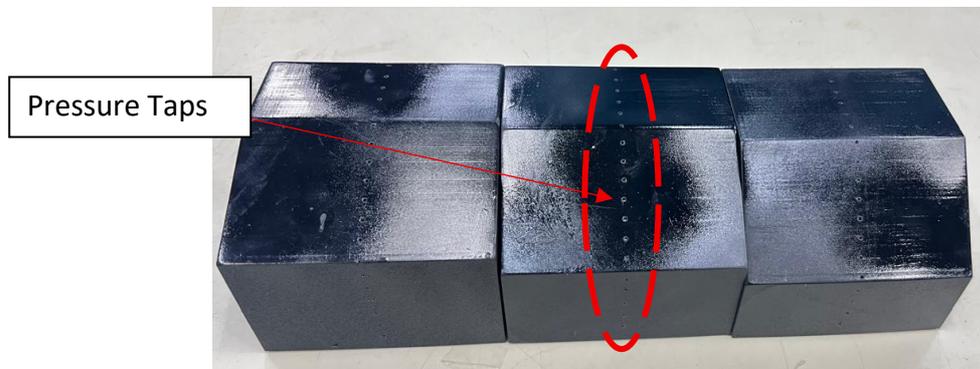


Figure 2: The rear sections of the Ahmed model with slant angle of 15°, 25°, and 45°.

The two measurements for this study are forces measurement using load balance JR3 and on-surface pressure measurement using pressure scanner FKPS 30DP. The model is bolted to a strut which is bolted to JR3 located beneath the test section for forces measurement. The pressure taps as shown in Figure 2 is connected to vinyl tube and connected to FKPS 30DP for pressure measurement. The aerodynamic forces and pressures measured are converted into coefficients using the equation shown below. The coefficients of aerodynamic forces such as lift, drag and side force are calculated using similar equation.

$$C_f = \frac{F}{\frac{1}{2} \rho V^2 A}$$

Where:

F is the net force (N),

ρ is the air density (kg/m^3),

V is the free-stream vehicle speed (m/s),

A is the reference area, which is frontal area for current study (m^2).

$$C_p = \frac{P - P_s}{\frac{1}{2} \rho V^2}$$

Where:

P is the on-surface pressure at points on model (Pa),

P_s is the reference pressure, which is the static pressure of freestream air inside the test section for the current study (Pa).

RESULT AND DISCUSSION

Figure 3 showing the result of forces measurement for the model under effect of the active flow control at different yaw angle. This yaw angle simulates the behaviour of the vehicle with steady blowing in cross-wind situation. At zero yaw, the reduced drag coefficient can be attributed to delayed separation and a narrower wake, consistent with the observed smooth pressure recovery on the slant. As yaw angle increases, the gradual rise in drag suggests that crossflow-induced asymmetry increases pressure drag due to wake deflection and enhanced lateral pressure gradients. However, the absence of a sharp drag increase implies that the blowing limits wake expansion and prevents abrupt breakdown of the shear layer.

The near-zero lift coefficient at zero yaw indicates that the steady blowing does not introduce artificial vertical force bias, which is an important consideration for practical vehicle applications. As yaw increases, the growing magnitude of lift suggests increasing asymmetry in surface pressure, particularly near the roof edges and rear slant. Despite this, the slope of the lift variation remains moderate, implying that the active flow control limits extreme pressure imbalances that would otherwise arise from large-scale separation.

The relatively smooth variation of side force with yaw indicates that steady blowing contributes to stabilizing the lateral pressure distribution. In uncontrolled cases, side force behavior often becomes nonlinear at higher yaw angles due to wake switching or vortex breakdown. The absence of such nonlinear behaviour in the present results suggests improved directional stability under yawed conditions.

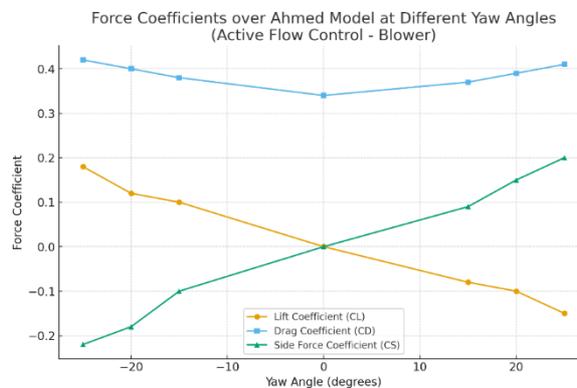


Figure 3: Coefficient of forces across yaw angle for Ahmed model with active flow control.

With steady blowing applied, the suction peak remains strong and relatively invariant with yaw angle as presented in Figure 4. This suggests that the blowing effectively energizes the boundary layer upstream of the slant, delaying separation and maintaining flow attachment even under yawed conditions. In the absence of flow control, previous studies typically report earlier pressure recovery and weaker suction at comparable yaw angles, indicating more extensive separation. The present result therefore supports the interpretation that steady blowing suppresses large-scale separation over the slant.

Downstream of the suction peak, a smooth pressure recovery is observed toward the rear of the model. The gradual recovery, rather than an abrupt increase in pressure coefficient, implies a reduction in separation severity and a more coherent shear-layer development. At higher yaw angles, minor deviations in pressure recovery appear, reflecting asymmetric wake development; however, these deviations are small compared to the overall pressure level, further reinforcing the stabilizing effect of the active flow control.

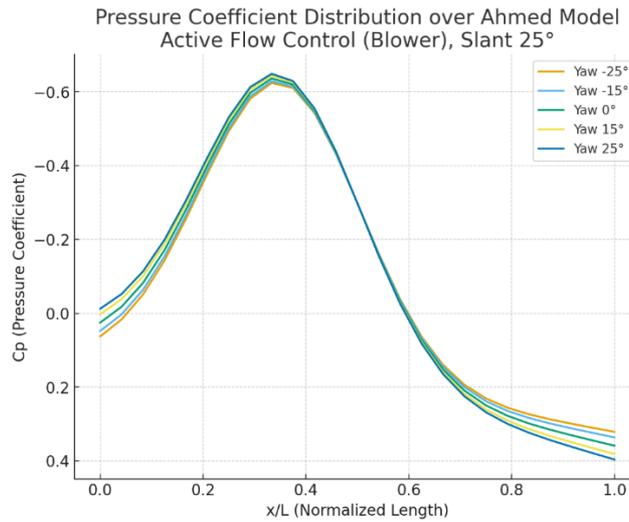


Figure 4: Coefficient of pressure along the centreline of Ahmed model with active flow control.

CONCLUSION

Taken together, the pressure and force coefficient results demonstrate that steady blowing applied to the top surface of the 25° Ahmed model effectively stabilizes the aerodynamic flow field. The control strategy reduces sensitivity to yaw angle, maintains strong suction and controlled pressure recovery over the slant, and moderates variations in drag, lift, and side force.

From an engineering perspective, these findings imply that steady blowing can enhance both aerodynamic efficiency and crosswind robustness. While unsteady or pulsed blowing may offer further drag reduction, the present steady blowing configuration already achieves significant improvements in flow attachment and force predictability, making it a promising baseline for more advanced control strategies.

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