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ВЛИЯНИЕ ИЗМЕНЕНИЯ ДЛИНЫ ЗАДНЕГО КРЫЛА НА ДИНАМИКУ АВТОМОБИЛЯ

EFFECTS OF CHANGING REAR WING LENGTH TO THE VEHICLE DYNAMICS

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В скоростных транспортных средствах аэродинамическая форма, передние и задние спойлеры, а также крыло создают дополнительные силы прижима для максимального увеличения тягового усилия. В данной статье представлены эффекты изменения длины заднего крыла на динамику автомобиля. Модель, использо-

ванная в этом исследовании, представляет собой двухдверное купе с задним крылом, у которого можно изменять длину средней части. Результаты показывают, что при большом угле атаки и выдвинутом назад крыле сила прижима значительно увеличивается. Также рассматриваются эффекты выдвижения крыла вперед. Эти результаты предоставляют важную информацию для разработки адаптивного заднего крыла, реагирующего по-разному на скоростной автомобиль.

In high-speed vehicles, the aerodynamic shape, front spoilers, rear spoilers, and wing generate additional downward forces to maximize the traction force. This paper presents the effects of rear wing length changes on the vehicle dynamics. The model used in this study is a 2-door coupe with a rear wing that can change the length of the middle part. The results show that the downforce increases significantly at a large angle of attack and the wing is extended backward. The effects of forward extension are also considered. These results provide crucial information for developing an adaptive rear wing that responds differently on the high-speed vehicle.

Ключевые слова: *аэродинамическое крыло, выдвижение крыла, вычислительная гидродинамика, динамика автомобиля.*

Keywords: *aerodynamic wing, wing extension, computational fluid dynamics, vehicle dynamics.*

INTRODUCTION

Aerodynamic factors play an important part in vehicle dynamics. The body shape, spoilers, and wings are considered in automobile design [1] to balance between the aspects of concept geometry and the aerodynamic factors [2]. One of the main goals is to improve the traction force while reducing the aerodynamic drag to increase the vehicle performance [3]. In high-speed vehicles, the engine power often exceeds the traction limit. To maximize the vehicle’s performance, it is important to enhance the traction capacity by either improving the grip coefficient of the wheels or increasing the total normal force of the vehicle. Rear wings are used to generate additional force in this situation. In this study, the angle of attack, and the change of wing length are subjected to investigate and analyze to see their effects on the vehicle dynamics.

VEHICLE AND WING MODELS

The study object was chosen as in fig. 1, and the Rear Wing profile as in fig. 2.

The vehicle is simulated at a speed of 100 km/h with rear wing angles of 0°, 5°, 10°, 15°, and 20°, under three conditions: No extension, Extension to front, and Extension to back. The Computational Fluid Dynamics (CFD) method is employed to analyze the aerodynamic effects of the Rear Wing on the vehicle dynamics. The 1:1 scale vehicle model is used for simulation. The RANS Realizable k-ε Two Layer model is utilized for its high computational efficiency (in terms of time and stability) and high accuracy [4–6].

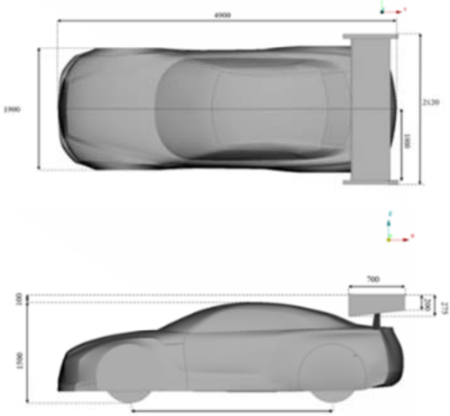


Figure 1 – Vehicle CAD model

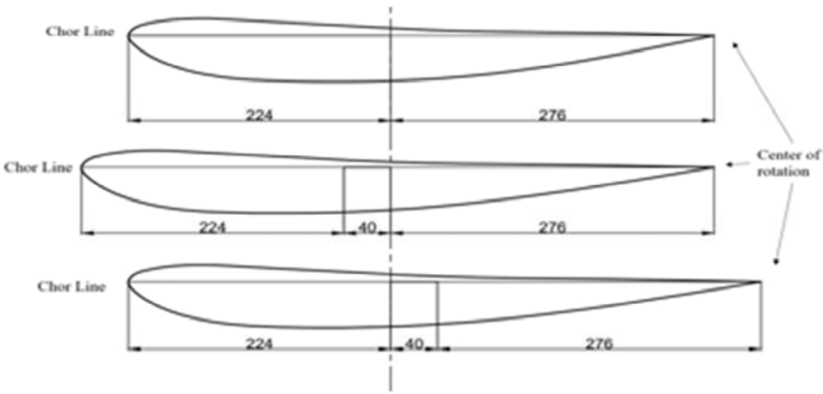


Figure 2 – Rear Wing profile

To examine the influence of varying the length of the Rear Wing on the aerodynamic and dynamic characteristics of the vehicle, the NACA 4412 airfoil shape is utilized due to its capability to reduce drag force [7, 8]. The length of the Rear Wing corresponding to each angle of attack is extended by, 40 mm both forward and backward, to ensure a comprehensive evaluation of the geometric impact on aerodynamics. The extension point of the Rear Wing is selected at a location with a relatively low curvature and is elongated along the Chord Line of the NACA 4412 Wing to minimize interference with the original shape, as shown in fig. 2. Additionally, the vehicle has a total mass of $G = 12000$ N and distributes the static weight equally on each axle. During the calculation process, the influence of rolling resistance force is considered, with a rolling resistance coefficient of $f = 0{,}015$.

The boundary conditions for the calculation are summarized as **Velocity inlet**: Magnitude and direction 27,7m/s and Turbulence intensity 2 % and Turbulent viscosity ratio 10, **Pressure outlet**: Gauge pressure magnitude 0 Pascal and Backflow turbulence intensity 5 %, **Wall Simulation Volume**: Wall-Non-slip, Wall Data Vehicle: Standard Wall, **Air properties**: Density 1,175 kg/m^3, **Reference Temperature**: 300 K.

Consider the forces affecting the longitudinal dynamics of the vehicle as depicted in fig. 3 below, equations (1) and (2) describe the reaction forces between the wheel and the road surface in the longitudinal direction:

$$F_{z1} = \frac{G \cdot b - F_D \cdot d + F_L \cdot (b - h)}{a + b}\ ; \tag{1}$$

$$F_{z2} = \frac{G \cdot a + F_D \cdot d + F_L \cdot (a + h)}{a + b}\ , \tag{2}$$

in which F_D is the aerodynamic drag force (N), F_L is the aerodynamic downforce (N), G is the static weight (N), a, b, the distribution of static weight onto the two axles of the vehicle, d is the height of the center of gravity for aerodynamic force, b is the distance between the static center of gravity and the aerodynamic center, F_{z1}, F_{z2} are the ground reaction forces.

On two-door coupe vehicles, often driven at high speeds with rear-mounted engines, the rear axle typically serves as the driving axle, generating traction to aid acceleration. With a road adhesion coefficient of φ = 0,7, we have the formula to calculate the maximum acceleration traction force for the vehicle:

$$F_{tt\max} = F_{z2} \cdot \varphi - F_D - F_{f1} - F_{f2} \ . \quad (3)$$

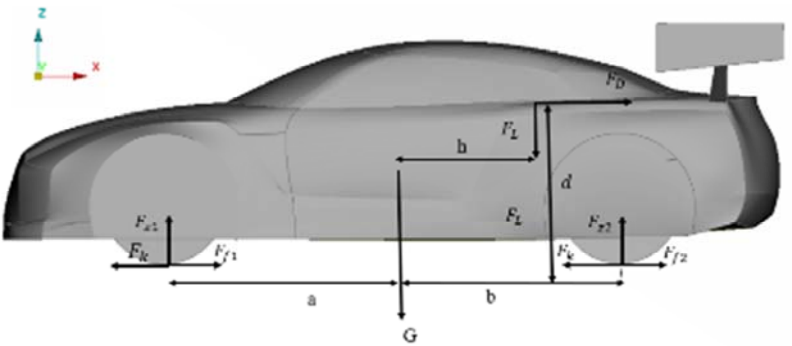


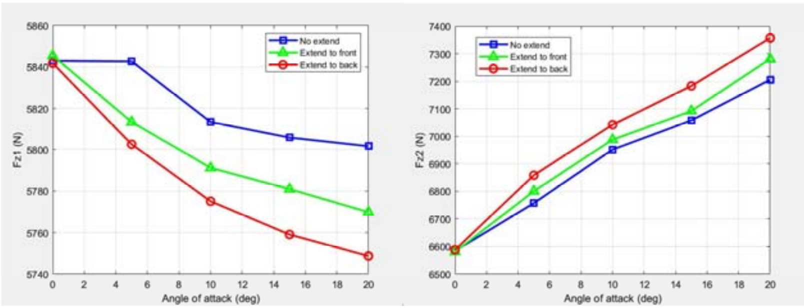
Figure 3 – Vehicle longitudinal dynamics model

SIMULATION RESULTS

As the angle of attack of the RearWing increases, the aerodynamic influence of the RearWing on the vehicle's longitudinal dynamics becomes stronger through significant changes in aerodynamic drag and lift forces. At the front axle, when the angle of attack is 0, extending the Rear Wing to the front or back does not significantly alter the reaction force between the wheel and the road surface. On the other hand, as the angle of attack increases, the aerodynamic drag force increases while the lift force decreases, leading to an increase in downforce and a tendency for the aerodynamic center of pressure to shift towards the rear of the vehicle.

Therefore, the reaction force between the wheel and the road surface at the front axle, F_z1, tends to decrease as the angle of attack increases. Extending the RearWing to the back enhances the downforce significantly, and the aerodynamic center of pressure tends to shift further rearward compared to extending it to the front. Consequently, when changing the length of the RearWing, the reaction force at the front axle tends to decrease, with a more pronounced decrease at the front axle as depicted in fig. 4, *a*.

Conversely, as the angle of attack increases and the aerodynamic center of pressure tends to shift rearward, the reaction force with the road surface at the rear axle increases significantly. This is because the downforce aerodynamic force concentrates more towards the rear wing. Therefore, RearWing Extend to back will have a higher effectiveness in increasing the reaction force between the rear axle and the road surface compared to Extend to Front, as shown in fig. 4, *b*.



a b

Figure 4– Graphs of the change in ground reaction force of the front axle (a) and the rear axle (b)

The acceleration capabilities of coupe vehicles are often of particular interest. Acceleration capability is primarily evaluated by the maximum longitudinal acceleration force that can be generated during motion. The acceleration force is calculated as the maximum traction force that can be generated at the driving axle minus the influence of resistive forces such as rolling resistance, aerodynamic drag, inertial resistance, and gradient resistance. Here, we assume the vehicle is operating on a flat surface (gradient resistance = 0) and moving at a constant speed of 100 km/h, so gradient resistance and inertial resistance can be considered negligible. Using the formula (3), the relationship between acceleration force and the angle of attack is shown in fig. 5. When extending the RearWing at a 0-degree angle of attack, the impact on the vehicle's acceleration capability is insignificant due to minimal changes in aerodynamic forces on the RearWing. However, as the angle of attack increases, the downward force (downforce) and aerodynamic drag force increase significantly. Hence, the maximum acceleration force tends to increase rapidly at small angles of attack from 0 to 10 degrees, reaching a peak at an angle of attack of 10 degrees. At larger angles of attack, the increase in acceleration force is not as significant.

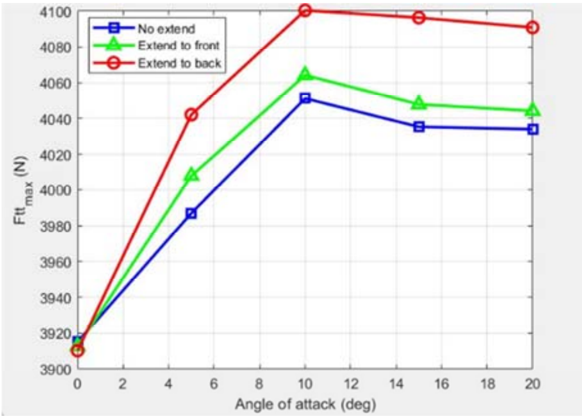


Figure 5 – Graph of maximum acceleration force

CONCLUSION

This paper has presented the simulation and analysis of rear wing extension on the vehicle dynamics. The 2-door coupe car model equipped with NACA 4412 wing was the subject of this study. The changes in the wing's length are investigated in three cases: original wing, forward extended, and backward extended wings. The angle of attacks was also considered. The results showed that increasing the length of the wing leads to increasing downforce and improving the traction force. This finding can be used as a reference when designing high-speed vehicles with responsive wings.

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