Műszaki Tudományos Közlemények vol. 15. (2021) 65–70.
DOI: Hungarian: https://doi.org/10.33895/mtk-2021.15.13
English: https://doi.org/10.33894/mtk-2021.15.13

Development of an Active Aerodynamic System for a Racing Motorcycle

Krisztián KUN,[1] Tamás SÁRKÁNY [2]

John von Neumann University, GAMF Faculty of Mechanical Engineering and IT, Department of Innovative Vehicles and Materials, Kecskemét, Hungary

[1] *kun.krisztian@gamf.uni-neumann.hu*

[2] *sarkany.tamas@gamf.uni-neumann.hu*

Abstract

MotoStudent is an engineering and economic competition for students to build a motorcycle that will take part in a real race on the Motorland Aragon track in Spain. The Kenji Racing Team, a student team from John von Neumann University, has been participating in this competition since 2016. The design of the motorcycle must be accurately documented towards to the competition organization, and economic and engineering tasks must be solved for the teams. In terms of engineering work, the development of innovation applied on the electric motorcycle is of paramount importance. Nowadays, one of the most popular development areas in motorsport is aerodynamics. Nevertheless, there are few studies about active aerodynamic systems. In our research we present the aerodynamics of motorcycles and the effect of passive and active wing systems on driving dynamics. With this knowledge, we detail the design steps of an active wing system.

Keywords*: active aerodynamic system, electric motorcycle, driving dynamics.*

1. Introduction

MotoStudent is an engineering and economic competition for students to build a motorcycle that uses its specified components and resources to compete on the Motorland Aragon track in Spain. Kenji Racing Team, a student team from Neumann John University, has been participating in the event since 2016. In 2021, the team will enter itself in the electrical category. The design of the motorcycle must be accurately documented to the race organization, and will receive special attention and evaluation of the innovation development applied to the motorbike. The aim is to increase the motivation to use innovation (formal aspect). The prototype must, of course, also be technically feasible. The innovative idea of the Kenji Racing Team is to develop an active aerodynamic package for the nose piece of the motorcycle pair. The technology is able to generate an ideal downforce according to the curves of the race track due to its active nature, thus achieving a positive effect on the driving dynamics of the motorcycle.

2. The effect of passive wing systems on the driving dynamics of a motorcycle

The vast majority of motorcycle developments started from MotoGP. The Suzuki team was the first to put wings on a motorcycle. The idea came from motorsport, where vehicle-mounted aerodynamic elements are used to generate downforce, significantly increasing traction. It can also be used to increase the cornering speed.

For motorcycles, the issue of downforce is more complex than for racing cars. The aerodynamic elements used in the latter are practically horizontal during cornering (apart from a slight tilt due to the compression of the landing gear), so that the downforce vector points all the way to the ground. When cornering motorcycles, the tilt of the vehicle must be taken into account to a significant extent, which can reach 60° compared to normal on the track. In passive systems, the wings tilt together with the motor, which simultaneously causes a change in the direction of the downforce vector (**Figure 1**).

3. The conception design of active wings that can be used on a racing motorcycle

Using the Optimum Lap software, we simulated the behavior of the motorcycle. The program provides an opportunity to plan the route, so by modeling the Aragon GP track, it is possible to examine the conditions in the race. The program shall specify the parameters of the motorcycle, including the motorcycle's mass, aerodynamic characteristics, battery type, motor power, tire data, and transmission ratios.

In larger corners, the motorbike reaches speeds of up to 175km / h. From this speed onwards, the wings c-n effectively generate a downforce. In the bend, however, after the vehicle body is tilted, the wings do not stand horizontally relative to the ground, creating unfavorable conditions. Thus, the wings can generate adverse effects that make it difficult to turn at high speeds [2].

The process can be prevented if the wings compensate for the tilt of the motor and are always horizontal to the ground. Thus, the downforce exerted by the wing continues to point in the same direction as the gravity (Figure 2).

3.1. The question of placement

The placement of the system on the motorcycle is a prominent issue, depending not only on the wing profile itself, but also on the vehicle body surrounding it and the distance from the wheel base. The body should direct the flowing air to the wings as much as possible, thus generating more downforce. It is more advantageous to place the system as forward as possible, because the force arm also increases if the distance from the wheelbase is increased (Figure 3). An important aspect of the placement is that the maximum profile width of 600 mm specified in the regulations is met.

By deepening the side of the body, the desired span was achieved. The beginning of the profile is designed to be arrow-headed to achieve the desirable airflow.

3.2. Mechanism of wing movement

According to the construction plan of the motorcycle, it can tilt by 50-50° in both directions, so the required angle of the wings was determined according to these values.

The moving rods are driven by an electric motor through a worm drive (Figure 4). The worm drive is necessary for several reasons. One is to

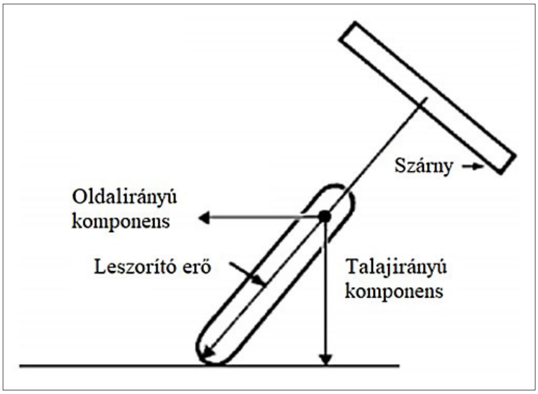

Figure 1. *The force relations with a passive aerodynamic system.* [1]

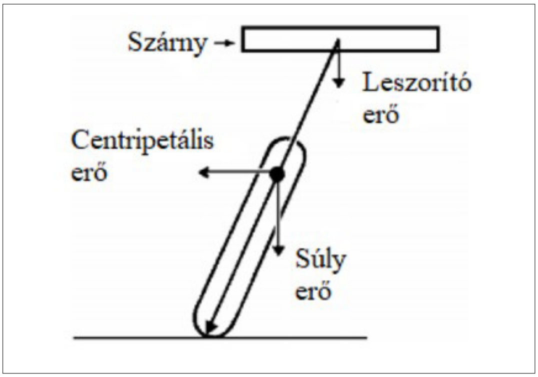

Figure 2. *The force relations with an active aerodynamic system.* [1]

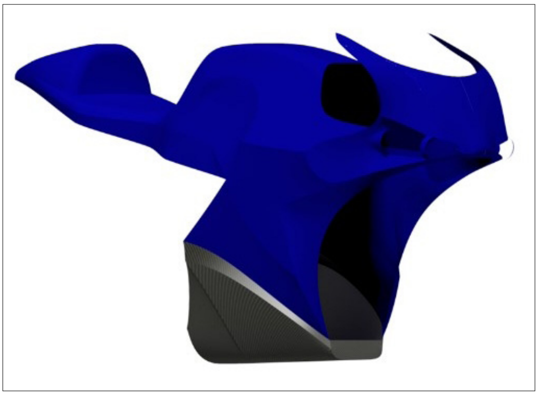

Figure 3. *3D model, designed for the wing system.*

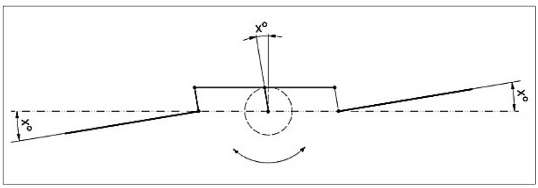

Figure 4. *Schematic figure of the moving mechanism*

reduce the motorcycle's speed and increase the torque, and the advantage of using a worm drive is its self-locking feature. As a result, the torque generated by the downforce cannot "rewind" the motor, so the wing always stays in the desired position.

Low speed is enough to move the wings. According to our measurements, a rider can make a 40° decision in about 0.5 seconds. This means that the worm gear must rotate 40° in 0.5 seconds. Thus, we obtain that 14 rpm is required to track the movement. Since the gear was selected on the basis of a catalogue, the higher value closest to the calculated value was used. Thus, a motor with a maximum speed of 30 rpm was chosen to operate the mechanics. [1, 3]

4. Construction design of the active aerodynamic system and investigation of the effect of the system on the motorcycle

According to preliminary calculations, the motorcycle will reach a top speed of 210 km/h. Therefore, this value was taken into consideration when selecting the profiles.

4.1. Wing profile selection

The wing profiles are designed for aircraft, so the calculations were performed as an airplane wing, which may remain in the air due to the dynamic buoyancy. In the case of a motorcycle, the line of reasoning changes so much that we want to generate a downforce, which can be obtained by reflecting all the coordinates of the wing profile and tilting it to the ideal α angle.

The (aero) dynamic buoyancy force (F_y) is the component of the force acting on a body placed in a flowing medium that is perpendicular to the direction of flow. The force component parallel to the direction of flow is called the air resistance (drag) (F_x) (Figure 5).). The wing profile is the shape of the wing section. A wing section (marked in yellow) is obtained by intersecting the wing with a plane of relative velocity of the vehicle and the air (ideally in the same plane) with a parallel plane intersecting the wing. The buoyancy and air resistance depend on the wing profile, as described in Equations (1) and (2). [3, 4, 5]

$$F_y = \rho \cdot v^2 \cdot A \cdot \frac{C_y}{2} \quad (1)$$

$$F_x = \rho \cdot v^2 \cdot A \cdot \frac{C_x}{2} \quad (2)$$

where:
- v relative speed of the flow and the machine
- A the wing surface
- ρ air density (natural constant)
- C_y buoyancy factor
- C_x drag coefficient

Of the wing profiles examined, "NACA6409 9%" shown in Figure 5 is the most appropriate, based on the preliminary criteria.

The simplest way to determine the magnitude of the investigated forces as a function of the relative velocities of the flow and the machine is to examine it in certain Re values. The missing values are approximated based on the points shown below (Table 1, Figure 6.).

Table 1. *Downforce and air resistance (drag) determined for the calculated speed values*

R_e ( )	v (m/s)	C_x and C_x	F_y (N)	F_x (N)
50 000	7	1.05 és 0.03	0.432	$1.24 \cdot 10^{-2}$
100 000	14	1.15 és 0.02	1.89	$3.29 \cdot 10^{-2}$
200 000	30	1.2 és 0.015	9.78	0.113
500 000	60	1.2 és 0.01	36.31	0.303

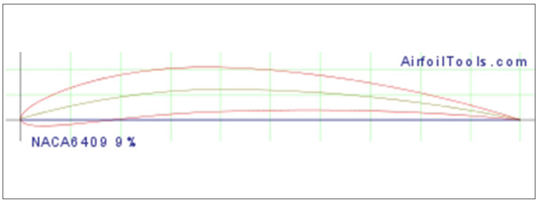

Figure 5. *The section of the selected profile*

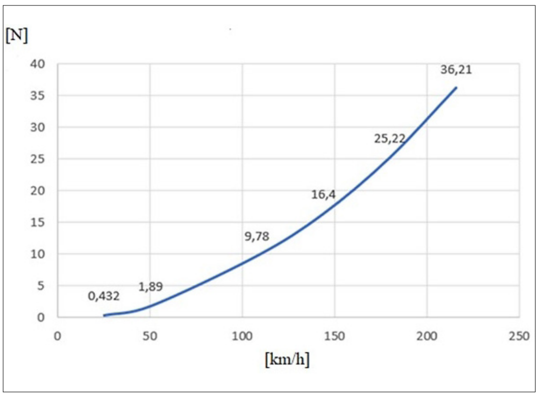

Figure 6. *The amount of downforce per wing as a function of speed*

4.2. CFD simulation on the wing profile

A 2D simulation study was performed using the downloaded outlines of the NACA profile. The results are illustrated in Figures 7. and 8. Ansys 17 Workbench software was used for the study. [6, 7, 8]

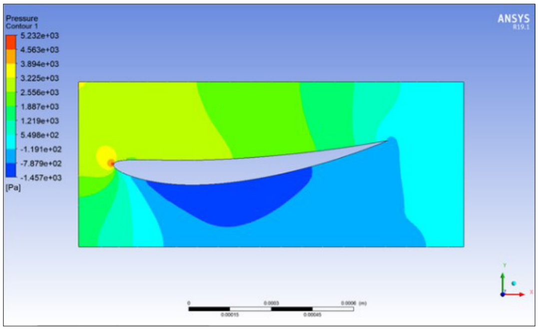

Figure 7. *The pressure around the profile at the maximum speed that the motorcycle can reach.*

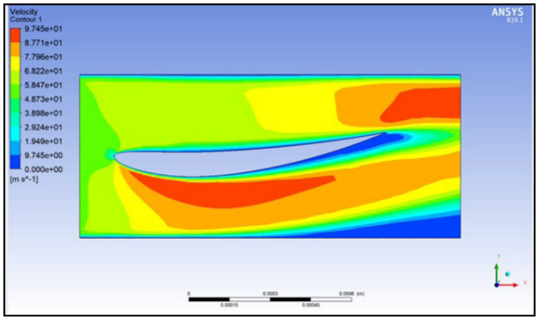

Figure 8. *Flow rate around the profile at the maximum speed that the motorcycle can reach.*

4.3. The design of the active wings

The design of the wing is slightly arrowed forward, with a baffle near the frame (on one-third of the wing) with wingtips bent at the edge by 30 degrees.

In our case, the forward arching of the wings is minimal, so we can speak of almost straight wings (arrowing is only beneficial in terms of increasing the surface area). Straight wings are most preferred at low flight speeds. Furthermore, air currents do not drift (reducing buoyancy) toward the wingtips, so no swirling flow occurs. [9]

Despite the reasoning mentioned above, a deflector is still added to one third of the wing, since, in our case, the angle of inclination of the wing can be changed perpendicular to the speed. Due to the change in the angle of inclination, despite the straight wing profile, drift of the air currents is inevitable at higher angles, so that the largest possible surface close to the motor frame will be able to create an effective downforce even when cornering.

Thanks to the wingtips that bend at 30 degrees, we can take advantage of the so-called phenomenon of vortex lift (Figure 9). kThis means that the wingtips that bend at 30 degrees create a real vortex (the true mass of rapidly rotating air is present in the vortex) under the wing, which increases the velocity of the air, thus reducing its pressure. Low pressure under the wing results in an increase in the downforce.

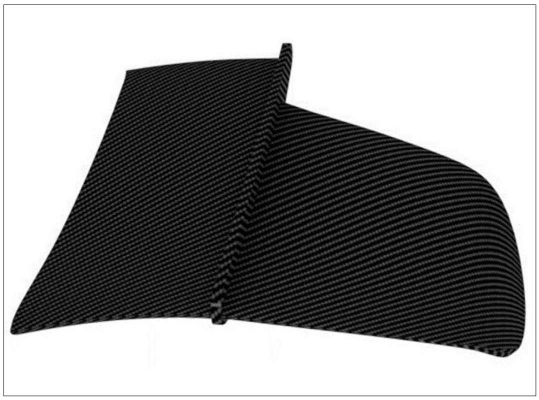

Figure 9. *3D model of the wing.*

Figure 10 illustrates a 3D model of the designed wing system. Furthermore, Figure 11 shows how the effective active aerodynamic package fits the body.

Figure 10. *3D model of the designed system.*

5. Control unit for active aerodynamic system

A programmable microcontroller electronics was designed to move the wings. Instead of discrete components, we used commercially available panels. The Figure 12 shows a schematic diagram of the system.

The system is based on an Arduino Nano programmable microcontroller. It allows the wings to be controlled depending on the inclination of

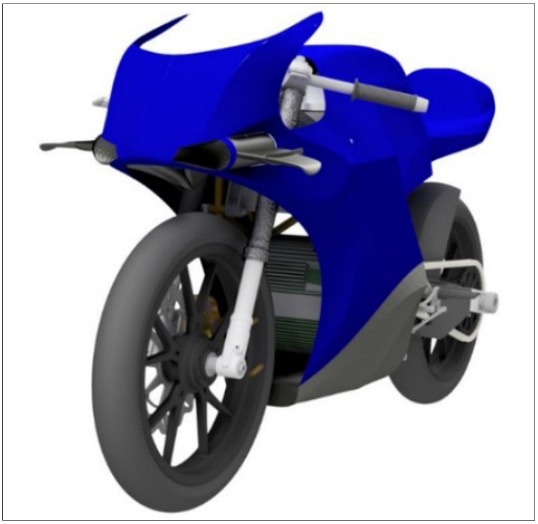

Figure 11. *AD assembly of the complete racing motorcycle, with the active aerodynamic package.*

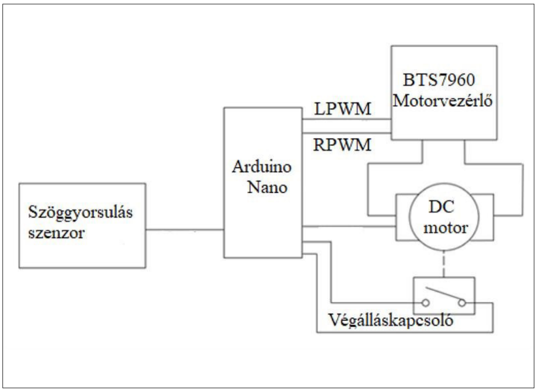

Figure 12. *Schematic figure of the controller.*

the motorcycle. The inclination of the motorcycle is measured by an MPU6050-M acceleration and angular velocity sensor. The wings are moved by a worm gear DC motor, which is driven by a BTS7960 H-bridge motor controller. The position of the wings can be measured using a position sensor on the shaft of the DC motor and limit switches mounted on the wing drive mechanism. After switching on the device, the system starts with a reference recording in order for the wing to find its actual angular position. Furthermore, in order to avoid damage to the structure (which may suffer due to excessive tilting of the sash), limit switches were mounted in the two end positions. **[10, 11]**

6. Conclusions

At high speeds, the aerodynamic buoyancy of the motorcycle can significantly reduce the weight on the front wheel, resulting in the wheel rising off the ground. This effect significantly impairs controllability **[12]** The designed system is for the stability of the motorcycle. With the downforce created by the wings, stability can be increased on fast track sections. The developed active aerodynamic system also eliminates the adverse effect of passive wings, which makes cornering difficult. The active system compensates for the tilt of the motor to keep the wings horizontal relative to the ground, so that the downforce continues to point in the same direction as the gravity. In the research, thanks to the simulation results, an ideal design and a compensating microcontroller system were created.

Acknowledgments

This research is supported by EFOP-3.6.1-16-2016-00006 "The development and enhancement of the research potential at John von Neumann University" project. The Project is supported by the Hungarian Government and co-financed by the European Social Fund.

References

[1] Foale T.: *Motorcycle handling and chassis design. Art and design*. 2006. 4–6.

[2] Veneri M., Massaro M.: *A free-trajectory quasi-steady-state optimal-control method for minimum lap-time of race vehicles*. Vehicle System Dynamics, 58/6. (2020) 933–954. https://doi.org/10.1080/00423114.2019.1608364

[3] Portaluri G., Tamburello M., Giordano S.: *A novel IoT-based architecture for self-adaptive aerodynamic flow control system for motorcycle*. In 2018 IEEE Global Communications Conference (GLOBECOM) 1–6. https://doi.org/10.1109/GLOCOM.2018.8648012

[4] Van Dijck T.: (2015). *Computational evaluation of aerodynamic forces on a racing motorcycle during high speed cornering*. SAE International Technical Paper, No. 2015-01-0097. https://doi.org/10.4271/2015-01-0097

[5] Sharp R. S., Evangelou S., Limebeer D. J. N.: *Advances in the Modelling of Motorcycle Dynamics*. Multibody System Dynamics, 12/3. (2004) 251–283. https://doi.org/10.1023/B:MUBO.0000049195.60868.a2

[6] Sharp R. S.: *The lateral dynamics of motorcycles and bicycles*. Vehicle System Dynamics, 14/4–6. (1985) 265–283. https://doi.org/10.1080/00423118508968834

[7] Sharp R. S., Limebeer D. J. N.: *A motorcycle model for stability and control analysis*. Multibody sys-

tem dynamics, 6/2. (2001) 123–142. https://doi.org/10.1023/A:1017508214101

[8] Desai S., Leylek E., Lo C. M. B., Doddegowda P., Bychkovsky A., George A. R.: *Experimental and CFD comparative case studies of aerodynamics of race car wings, underbodies with wheels, and motorcycle flows*. SAE Technical Paper, No. 2008-01-2997. https://doi.org/10.4271/2008-01-2997

[9] Cocco G.: *Motorcycle design and technology: how and why*. Giorgio Nada Editore, 1999.

[10] Badamasi Y. A.: *The working principle of an Arduino.* In: *2014 11th International Conference on Electronics, Computer and Computation (ICECCO),* IEEE, 1–4. https://doi.org/10.1109/ICECCO.2014.6997578

[11] Raymer D.: *Aircraft design: a conceptual approach.* American Institute of Aeronautics and Astronautics Inc., 2012. https://doi.org/10.2514/4.869112

[12] Sharp, R. S.: *The stability and control of motorcycles.* Journal of mechanical engineering science, 13/5. (1971) 316–329.