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Team First Report

Introduction:

Aerodynamics is a major component of science and technology in the sport of cycling. The effect of drag on a cyclist can have a major impact on speed, whether it be an instantaneous effect or a long term, compounding outcome. The purpose of this first team assignment was to visualize how air moves along tires on different and opposite spectrums of cycling, which is mountain biking (mtb) and road biking. We were able to see a stark contrast between these two bikes, as both the variance of rim depth and tire width were pronounced in their roles upon aerodynamics. Both bikes were placed an equal distance from a fog machine at separate times and recorded as fog flowed onto the front wheel. The videos depict the following: a side by side cropped comparison of the road and mtb wheel, a full view of the mtb wheel, and a full view of the road wheel. Multiple attempts were made to visualize the flow, starting with a bird's eye view, then from behind, in front, and eventually on the right side. Zach Cates and I shot both in both photo and video formats, and we decided that video was much more effective at visualizing this flow. Zach initially took photos on the bike's left side (from rider orientation) and I on recording on the right. After we decided on using my camera for video recording, I controlled the video settings, timing of the fog machine, and lights while Zach held the bike stable and made quick adjustments if necessary.

Materials: Apparatus and Flow:

Figure 1 depicts the setup, where both bikes were placed on a Garmin Tacx trainer stand 3 in high to keep the wheel stable while positioned roughly 6 to 8 in from the fog machine, which was elevated on a box 15 in high. The tripod was distanced 47 in perpendicular to the wheel base, and was set at 43 in with its base tilted 5 degrees downward. A circular, 5 in diameter light source was positioned directly in front of the fog machine on the ground, titled roughly 30 deg to illuminate the fog flowing from the machine, onto the tire, and past the wheel.

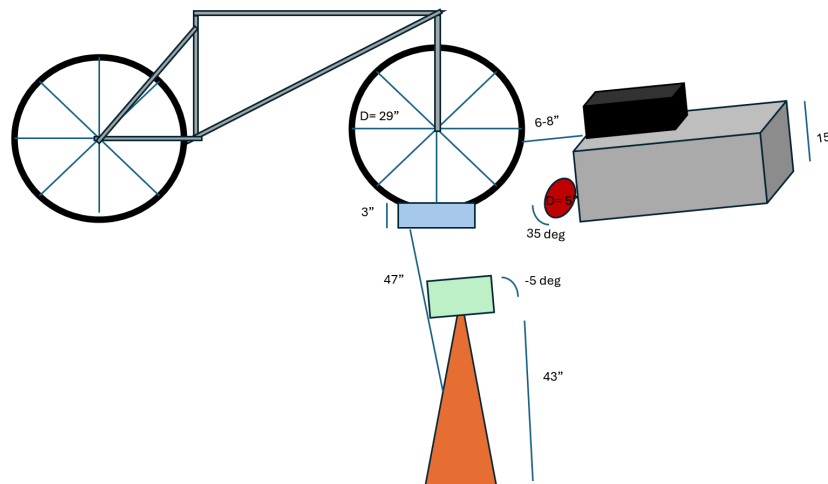


Figure 1: Design setup and measured distances.

The machine was supplied to us by Professor Sunberg, and is called the Ground Fogger Machine FLL-400 from Heshan Lide Electronic Enterprise Company LLC. This machine operates on 120V and uses 400W of power, with a small 5x5x3 in sized internal box for fog accumulation and 3.5 x 0.75 in nozzle for fuming. The fog used was a supplied, medium dense fog titled, “DJ’s Party Fog Juice”, with its main ingredients being water and glycerin. Per cycle of testing, the machine would take between 3-4 minutes to generate the fog in its storage, and would give about 1.5 minutes of fog roll. Both bikes had a wheel diameter of 29 in (700c), but the road bike tire is a smooth, 30 mm wide Pirelli P-Zero RS while the mtb tire is a knobby, 2.4 in wide WTB Ranger—it is important to note that mtb and road bike tires are given in different units due to inherent customs, but a 2.4 in tire is equivalent to roughly 60 mm. Both tires were inflated to rider specifications and further rim specifications and details are as follows in Table 1.

Bike	Wheel	Rim width (internal, external mm)	Rim Depth (mm)	Tire Choice and Width	Spoke Count	Tire tread	Inflated Pressure (PSI)
Road bike (Factor Monza sz 54)	Elite Drive Helix 57 CS	29,37	52	Pirelli PZero RS (30mm)	21	Smooth	63
Mountain Bike (Specialize d Epic 7, sz M)	Control SL VI Solix 29in Carbon Boost Wheel	21,31.8	25	WTB Ranger (2.4”)	24	Knobby	32

Table 1: Information of both bike wheels and tires. Units are given in the description or with the value.

Comparison: Drag and Turbulence

From the side by side comparison, the difference between the road and mtb tire was quite distinguishable. The road tire left slight flows but the vortices still were quite streamlined and the direction of flow still continued on past the wheel, while the mtb tire dragged much of the air and left swirling vortices in its wake. Both tires did change the direction of airflow upon direct contact, but the road tire positions the flow in a more definite direction and does not change the direction too much, while the mtb tire has some air flowing directly downward to the ground and other parcels moving around the tire and outwards. When analyzing these tires for aerodynamics, we can define the variables at play and input it into a equation used normally for a rider and bike to calculate aerodynamic drag (R_a), which is : $R_a = 1/2 S.C_x.p.v_a^2$, where S is the frontal area of the rider and bike combined, C_x is the coefficient of drag, v_a is the relative speed of the cyclist to the air, and p is the density of air ¹. Although this equation is meant to calculate the rider and bike as a system, we can infer that the difference in flow comes down to the inherent difference in bike disciplines, mechanics, tires, and rim profiles; the road bike is designed to move fast and maintain high speeds, where the drag (C_x) from the rim depth is less

and the tire and rim width has less frontal area (S), while the mtb is designed to absorb shock and maximize grip on uneven terrain, leading to a large surface area and multiple contact patches/knobs along the tread that grab and distort the flow of air.

When discussing flow, we can only roughly calculate the Reynolds number given the uncertainty in wind speeds from the fog machine, but we estimate it to be roughly 7 miles per hour. We chose mph to relate it directly to the bike application, but for a fog machine at this size it would typically be in cfm. If we define a parcel of fog to be travelling at 7mph (3.13m/s), ρ to be 1.02 kg/m^3 , μ to be $1.85 \times 10^{-5} \text{ Pa} \cdot \text{s}$ (at night, ambient temp is cooled to around 20 degC), and the hydraulic diameter of the vent duct is 0.0314m, then Re should be

$$Re = \frac{\rho V D_h}{\mu} = \frac{(1.15)(3.13)(0.03138)}{1.85 \times 10^{-5}} \approx 6,110$$

An $Re > 4000$ depicts turbulent flow, which is what is happening in this testing. We can assume more turbulence from the mtb testing relative to the road bike due to the increased formation of vortices formed from the wider tire and higher C_x value. If we were to examine the impact of rim depth on this experiment, past studies have shown that varying rim depths of bikes in the road discipline account for a 2-3% reduction in net aerodynamic drag, leading us to assume that the difference in a 52mm rim depth against a 25mm depth will account for a drag reduction of more than 3%². Furthermore, when equating this test to the net savings on aerodynamic drag of the complete system, wheel and tire choice combined have a 10-15% impact on drag reduction savings². Although the road bike tire did outperform the aerodynamics of a mtb tire, it is crucial to note that the rolling resistance can further impact the drag from these tires, and that road bike tires have historically increased overtime while also increasing the average speed; because road infrastructure contains more debris and gaps, narrower tires will be disrupted more than wider tires, which have a larger contact patch and can roll over or absorb more bumps and thus roll faster³. For real world testing, finding the most optimally aerodynamic tire will vary much more on the terrain of the course.

Visualization: Environment and Lighting

Air flow was captured as fog blowing from the machine directly onto the wheel. The materials, dimensions, and setup were described above and in Figure 1, but this experiment was done between 6-7:30 pm MT, in a garage with the door closed. The outside air temp was around 20 degC. Lighting was the main problem in this experiment, as the flow could not be seen under a normal led bulb light, but we made adjustments and used a red led, 5 in diameter, usb alarm clock that illuminated the flow in pitch black darkness. The light source used is [linked here](#).

Formatting: Video and Postprocessing

A video format was used as it best depicted the flow over time. We recorded around 1min of flow per test, and varied the focus every 15 seconds just in case the focus was initially wrong; 15 seconds is enough time to gauge the motion of the flow. The camera was shot on a Sony A7ii with a Tamron 17-28mm f/2.8 lens, with the camera being a full frame mirrorless body (35mm format). The phenomena was recorded at its most zoomed in (28mm, 75deg FOV) from 47 in away and shot at full HD (1920x1080p) 60 fps. Camera settings were f/2.8, iso 3200.

Postprocessing was done on darkroom, where I adjusted the contrast and black point to visualize the smoke outline best, and raised the saturation to color the body of the smoke so that it was visible. The sharpness and brightness was raised due to the grain/noise and dark setting. The image was cropped to exclude the entire setup and show only the fog and tire contact.

Review: Image Satisfaction and Impact

The image does effectively show the movement of air on these tires, and highlights the drastic difference between a road and mtb tire. I believe that we had an effective setup given the lack of resources compared to traditional testing. I did not appreciate the drop in quality as we uploaded our files onto youtube, as well as the conversion between the camera file and the necessary file format for darkroom. The main limitation was in the camera and our inability to get the right settings/illumination, but I believe that the physics was shown well if seen in person, and slightly difficult to understand from the videos. I would improve this by having a denser fog, faster flow, dyed or illuminated fog, and a more capable camera or lighting system if this were to be recorded in the dark. I would love to visualize the aerodynamics of a road cyclist under different positions—from an “aero-tucked”, in the drops, or upright position just like what you can see in some wind tunnels. We first attempted this but the density and output of fog was not enough.

References:

¹Bertucci, W. M., Rogier, S., & Reiser, R. F. (2013). Evaluation of aerodynamic and rolling resistances in mountain-bike field conditions. *Journal of Sports Sciences*, 31(14), 1606–1613. <https://doi.org/10.1080/02640414.2013.792945>

²Malizia, F., Montazeri, H., Hespel, P. J. L., & Blocken, B. (2017). The influence of the rim depth to the aerodynamic performances of a wheel: a numerical study. *Journal of Science and Cycling*, 6(3).

³Zeddy. (2024). Do Wider Tires Mean Faster Speeds? A Comprehensive Analysis. Tideace, <https://tideacebike.com/blogs/news/do-wider-tires-mean-faster-speeds-a-comprehensive-analysis?srsId=AU7gw4VDd2k5HQMqAcuCG-7uEVLNOH8KDtKrjQBkGi8H7QNRfYvdcVjc>