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Strength in Numbers

I Introduction and Background

In a race, speed is everything. Every decision from what equipment should a racer take on a particular day to how much body hair should a cyclist have is taken into consideration. The end goal of this: to be as aerodynamic as possible. Cyclists in particular are known for grouping up in races. As much as this may look like a team huddle, the advantage of this strategy reaps great rewards.

When watching cyclists race, it may seem as if they are tailgating one another. However, this strategy, known as drafting, can significantly reduce drag for the bikers behind while at the same time aiding the leader of the pack. Examples of this phenomenon can be seen in nature, specifically in geese who fly in V-formation. The goose in front creates a lift force for the others behind him, allowing them to exert less force. In racing sports like NASCAR, racers stay close behind with goals to propel themselves ahead of the driver in front of them. A cyclist's ultimate goal is to use their aerodynamic advantage to slingshot themselves into the lead. While the leader does get a boost due to the high pressure distribution from the cyclists behind him, ultimately, the bikers behind the leaders are benefiting the most (Gaitonde). Therefore, in competitive racing, many cyclists try to save their energy by staying behind another cyclist for a final push near the finish line.

One way that cyclists do this is by utilizing a technique called "The Belgian Tourniquet" it involves a constantly rotating circle of cyclists where they move from the lead to the back. This allows the cyclists in the rear to utilize the reduced drag force created by the front cyclist to propel themselves forward or conserve energy by doing less work while maintaining the same speed. An eddy is a current that is travelling in a different direction than the rest of the flow. So in the case of bicyclists, the front cyclist forces the wind to go around him/herself leaving the area behind the cyclist open for an eddy to form. The rear cyclists then fill in the space of the front cyclist, reducing the drag force upon themselves. This way, the cyclists are more equally using energy since the entirety of the group takes turns providing the buffer to the wind and using the reduced drag to their advantage. This paper analyzes how bikers can maximize their energy efficiency and speed using the reduced drag forces caused by drafting.

II Data

Our process for gathering data involved two parts. The first part consisted of researching concepts and equations. This was done in order to ensure that accurate information is being delivered. The second part involved designing and running fluid simulations about a variety of scenarios involving a varying number of bikes.

II.I Computational Fluid Dynamics

We computed fluid simulations using SolidWorks. We began our operation by having a plate acting as the ground. Next, we made a model of a bike and mated it coincident to the ground plate in an assembly.

To begin our simulation, we chose a value of 15 m/s for our wind speed, which is based on the average speed of a cyclist on flat terrain. Next, we added boundary conditions to ensure realistic conditions. For our results we opted to calculate the drag force acting on the bikes in the z-direction (right to left). Finally, we added two more configurations, one with two bikes and one with four, to support our claims regarding cyclists drafting.

II.II Equations

The drag coefficient of an object, C_D, is given by

$$C_D = \frac{F_d}{\frac{1}{2}pU^2A} \tag{1}$$

In which F_d is the drag force, p is the density, U is the upstream velocity, and A is the frontal area, or the area that is perpendicular to the stream. The drag coefficient is a number used to model airflow about an object that takes into account all of its complexities (NASA).By finding this number, we can compare how aerodynamic a singular bike is compared to the pack bikes.

Another equation that can be used to show the impact of drag is the work equation. Work, W, defined as

$$W = FD \tag{2}$$

is the product of Force, F and distance, D. In other words, work is the amount of force applied over a specified distance.This is equation will be useful in comparing the amount of energy each cyclist needs to exert based on their position in the pack.

II.III Tables and Figures

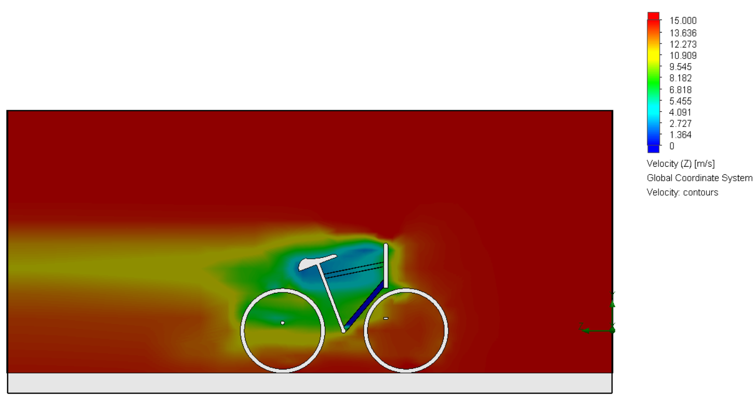

Figure 1: The airflow about a singular bike

Goal Name	Unit	Value	Averaged Value	Minimum Value
SG Force (Z)	[N]	6.462128518	6.574259434	6.462128518

Figure 2: The drag force exerted upon singular bike

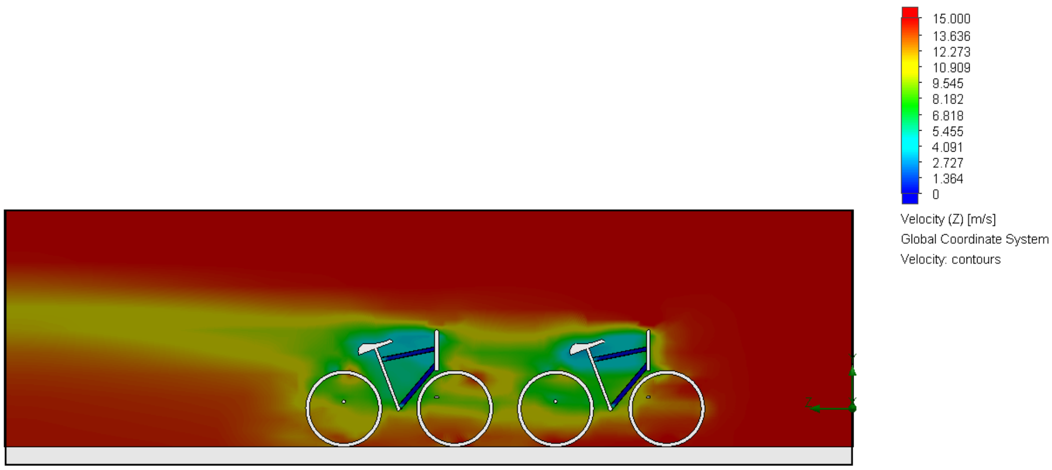

Figure 3: The airflow about two bikes

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
SG Force (Z) Bike 1	[N]	5.331568036	5.373278717	5.331568036	5.424590125
SG Force (Z) Bike 2	[N]	3.897010546	3.937648447	3.890447551	4.076262246

Figure 4: The drag force exerted upon two bikes

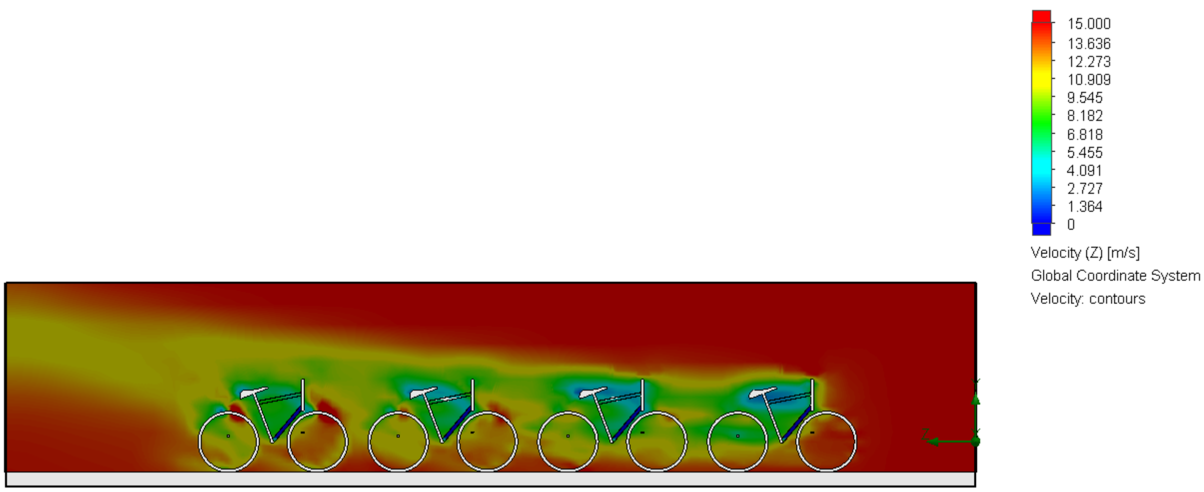

Figure 5: The airflow about multiple bikes

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value
SG Force (Z) Bike 1	[N]	5.70165712	5.720249001	5.701657117	5.744101585
SG Force (Z) Bike 2	[N]	3.73756018	3.759401734	3.732314107	3.816131907
SG Force (Z) Bike 3	[N]	2.66795509	2.660285372	2.646123145	2.674131392
SG Force (Z) Bike 4	[N]	2.54267567	2.548818573	2.51743792	2.572008958

Figure 6: The drag force exerted upon multiple bikes

III Results and Analysis

The most important data point from figures 2, 4, & 6 are the "Value" column. The "Value" in fig. 2 represents the drag force fully applied upon a singular bike. The drag force seen in Fig. 1, the singular bike, is equal to 6.46N. To demonstrate that every bike involved in a pack benefits from drafting, a value lower than 6.46N will be given from the simulations for every other model. These value will be lower than 6.46N because a drag force is a force that resists motion and the goal of drafting is to minimize drag force. The second model, figure 3, demonstrates what happens when multiple bikes are considered in the simulation. In this case, the lead bike has an applied drag force of 5.33N and the second bike has a drag force of 3.94N. When there are 2 bikes in the pack, the lead cyclist has their drag force reduced by 16.9%. The second bike has its drag force reduced by 38.4% when compared to a bike not participating in drafting. As more bikes group together to draft, the bikes in the rear are impacted even less by the drag force. As seen in figure 6, the front bike has a drag force of 5.72N and the rear bike has a drag force of only 2.55N. These are different by a factor of 2.24, while in the simulation with only 2 bikes, that factor is 1.58.

By using the work formula and the drag force calculated by the simulations, a value can be gathered for how much more work a cyclist has to do based on their location in the pack while drafting. In the Tour de France, a popular race for professional cyclists, they ride 3,414 kilometers. So, using the work equation, we see that a cyclist that travels alone will have to do an estimated 22,000 kilojoules worth of work just to counter the drag force. Comparatively, a bike in the fourth position of a bike would only have to do 8,700 kJ worth of work to counter the drag force, about $\frac{1}{3}$ the amount.

IV Conclusion

The data suggest that both the leader of a pack of cyclists as well as the cyclists in the to the rear benefit from drafting. Additionally, we see that drag is reduced further for the rear cyclists as more join the pack. So, as we see in the real world, it is logical for a few large packs of cyclists to form rather than several small packs, as this will decrease the drag force the most for the largest amount of cyclists. Due to the symbiotic relationship of drafting, teams could most effectively use this knowledge to their advantage by rotating the front member of the pack to the rear and taking advantage of the speed boost due to reduced resistance to "slingshot" fellow team members to the front of the pack, therefore allowing the previous leader to perform less work while maintaining the same speed.

Appendix

% drag reduction of bike 1

$$\% = 1 - \frac{5.37}{8.46} = 0.169 * 100\% = 16.9\%$$

% drag reduction of bike 2

$$\% = 1 - \frac{3.98}{6.46} = 0.384 * 100\% = 38.4\%$$

Work due to drag force

$$3414[km] * 6.46[N] = 22000kJ$$

$$3414[km] * 2.54[N] = 8700kJ$$

Works Cited

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