Team Vitesse

Design & Engineering Portfolio

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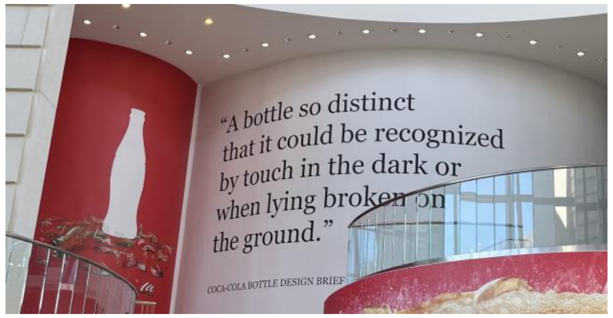
VARDHAMAN CREATIONS
The Complete Satisfaction...

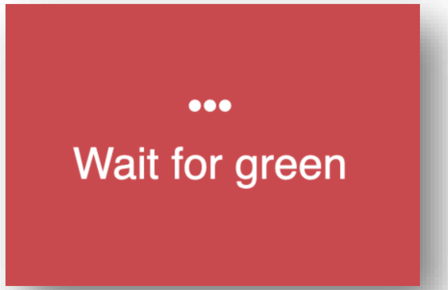
Introduction

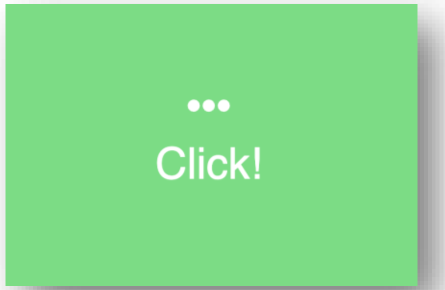


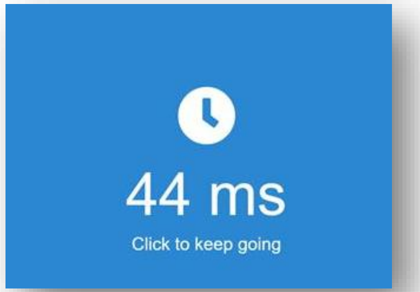
"A bottle so distinct that it could be recognized by the touch in the dark or when lying broken on the ground." This was kept in mind when designing the Coca-Cola bottle. When we were creating our team's identity, we wanted it to be extremely unique. The shape of the hammerhead inspired our car, thus the name. Our team name, 'Vitesse' which is French for speed, represents our goal, which is to be the fastest in the competition. Our color theme, which is matte black and a glossy dark purple shows power, confidence and elegance. We believe that our team identity is distinct enough, but we'll let you be the judge of that (pun intended). This competition has been a rollercoaster, with many highs and even more lows and I feel like it's taught us a valuable lesson about life- 'Nothing ever goes the way you expected it to, and sometimes, that's a good thing. '

OUR TEAM MEMBERS:

Lakshya Agarwal: *Designer, Co-Sponsorship Manager*
Ayan Sur: *Sponsorship Manager*
Aarav Sareen: *Enterprise Portfolio Manager*
Ryaan Verma: *Project Management Portfolio Manager*
Suraj Gupta: *Design & Engineering Portfolio Manager*







REACTION TIME TEST:

To determine who had the fastest reaction time for the race launch, we conducted a reaction time test among our team members. The highest score was achieved by Ryaan, with an impressive reaction time of 44 milliseconds. The test was carried out using the website https://humanbenchmark.com/tests/reactiontime, and the team's average reaction time was approximately 200 milliseconds.

We also attempted to measure our reaction times during the official testing day. Although the results appeared to be below 100 milliseconds, the timing equipment was malfunctioning at the time, so we were unable to obtain accurate measurements.

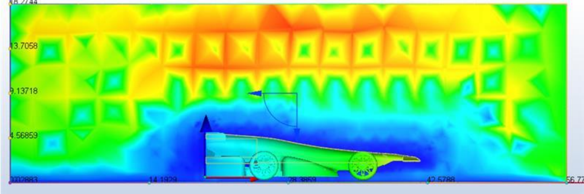
PIT DISPLAY:

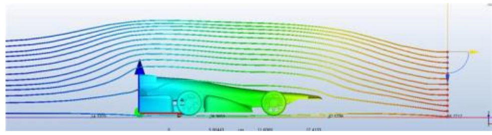
The pit display required careful planning to ensure that all elements fit within our budget. As part of the display, we included business cards from two of our sponsors—SURJ Enterprises and Strategy Pluto—as well as custom business cards designed for our team. In addition, we arranged for the production of custom pens, a tabletop standee, and a full-size standee to enhance the overall presentation and professionalism of our pit display.

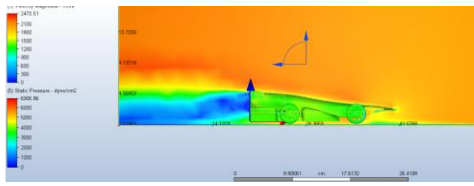
Date	Description	Income	Expense	Net Balance
	Sponsors:	₹23400		₹23400
04/04/25	Vardhaman Enterprises	₹8200		
05/04/25	Strategy Pluto	₹8200		
06/04/25	TAB	₹5000		
06/04/25	Teammates	₹2000		
06/04/25	Car		₹13100	₹10300
10/04/25	Merchandise		₹5316	₹4984
	Business cards			
	Pens			
	Caps			
	Stickers			
14/04/25	Flexes		₹500	₹4484
15/04/25	Testing		₹700	₹3784
16/04/25	Standee		₹600	₹3184
17/04/25	Pit Display		₹700	

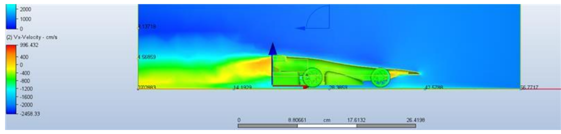
Budget Sheet

CAA (Computer-Aided Analysis)





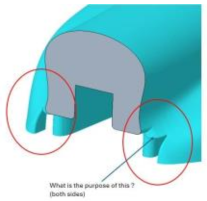


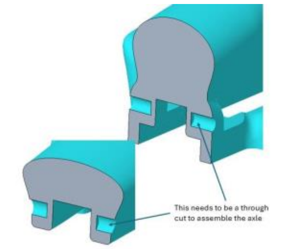


The software being used
The main software to evaluate the car is Autodesk's Computational Fluid Dynamics software (CFD) which provides valuable insight into the efficiency of the design of the car. It runs a fluid simulation over the car to check for areas which can be improved in terms of aerodynamics.

Autodesk CFD (Computational Fluid Dynamics) is a simulation software used to enable engineers and analysts to simulate and forecast how liquids and gases will act under different conditions. It allows one to simulate fluid flow, heat transfer, and other physical phenomena of relevance, gaining important insight for product design optimisations as well as minimising the expense of physical prototypes.

Key Features
- Fluid Flow and Thermal Simulation: Perform 3D fluid flow and heat transfer simulation to evaluate and optimise designs for performance, efficiency, and safety.
- User-Friendly Interface: This interface provides customizable configurations and a design study environment that enables users to compare design options easily and comprehend the effect of design decisions.
- Integration with CAD Tools: Directly supports all major CAD tools like Autodesk Inventor, Fusion 360, Revit, Pro/ENGINEER, and SolidWorks and simplifies the design to simulation workflow.
- Automation and Scripting: Enables automation via APIs, allowing repetitive processes and intricate workflows to be optimised.
- Advanced Meshing and Solving: Includes adaptive mesh size, scalable solvers for big simulations, and remote, high-performance, and cloud solving options.
- Visualisation Tools: Adds cross-sectional planes, particle tracing, iso surfaces, and wall calculators to visualise and analyse simulation results.
- Export to FEA: Export results of simulation as boundary conditions for additional finite element analysis (FEA).

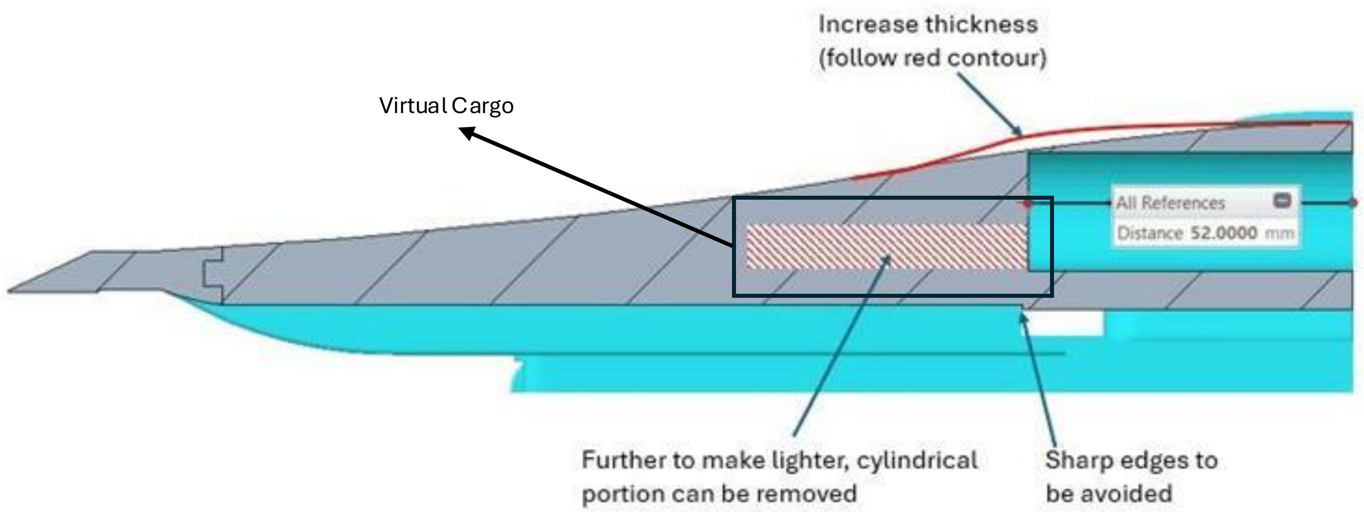


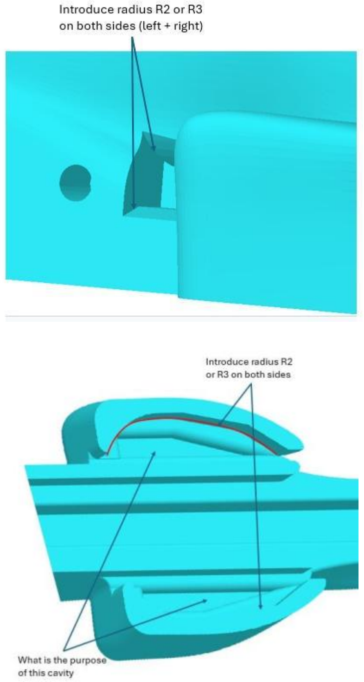


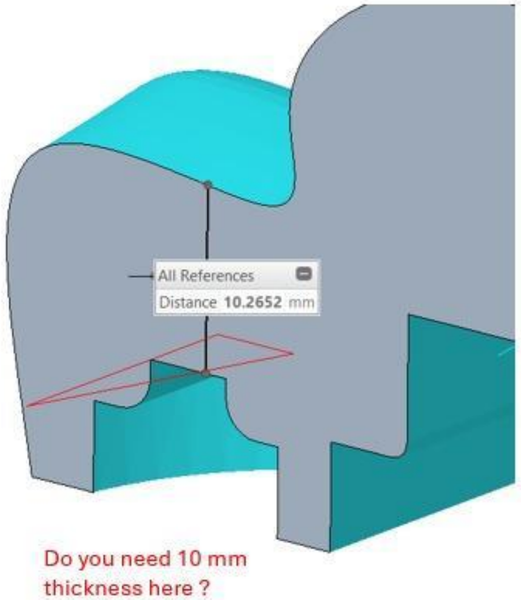
Typical Applications
- Product Design and Optimisation: Forecast product performance, verify behaviour, and optimise designs prior to manufacture.
- Thermal Management: Model electronics cooling and HVAC systems for occupant comfort in building and MEP (mechanical, electrical, plumbing) applications.
- Flow Control and Free Surface Modelling: Model complicated flow situations, such as free surface motion and motion simulation.

Usability and Target Audience
Autodesk CFD is especially famous for its ease of use for users who are not necessarily CFD specialists. It automates much of the simulation process, including mesh generation and solution control, so that it is easy for designers and engineers to get solid results without extensive knowledge of CFD theory. Yet, even experienced users can still access and modify detailed simulation parameters as necessary.

We also evaluated the STEP file of the car to check for any unnecessary cavities and overall design efficiency.







CAM (Computer-Aided Manufacturing)

The machine

Although our team didn’t directly operate the CNC machine, the car was manufactured using it, and this step played a huge role in shaping our final product. A CNC (Computer Numerical Control) machine is a sophisticated piece of machinery designed to cut accurate shapes from solid objects, and in F1 in Schools, it's imperative for converting car models on a computer into cars that are actual, light in weight, speeded up, and accurate according to the plan. Our car began life as a solid block of polypropylene, which was drilled out to shape with a 6mm diameter drill bit on a CNC router. The block itself is specially dimensioned for this competition, and the machine shaped it out to computer-accurate instructions.

The machine that made our car was the Denford 1000, a small but powerful 3-axis CNC router. It's particularly prevalent in academic environments and is made for safe, consistent use when dealing with plastics, wood, and other materials. Although we didn't operate the machine directly, we created the car in Fusion 360, a CAD (Computer-Aided Design) program. That design was then translated into manufacturing instructions through CAM (Computer-Aided Manufacturing) software in the form of a STEP or G-code file. These files are essentially the blueprint for the CNC machine, telling it exactly where to cut, how deep, at what speed, and in what order. This means the machine can produce a car that is an exact replica of the digital version we designed, down to the smallest detail.

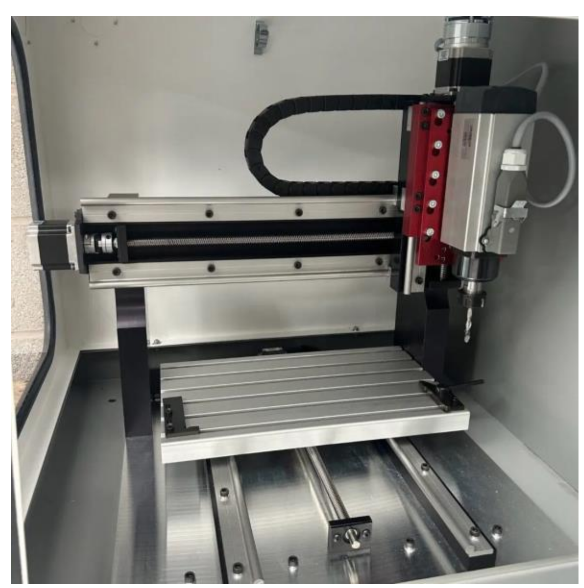
A CNC machine like the Denford 1000 is capable of making very precise cuts. That matters because tiny faults in the body of the car can have a significant impact on how air travels around it, which has consequences for speed, stability, and performance. Particularly in a contest like F1 in Schools, where fractions of a second are critical, possessing a body that is smooth and precisely shaped can make a major difference. Also, because CNC machining is done mechanically, there's far less room for human error—each car is built precisely the same way every time, which contributes to consistency and quality.

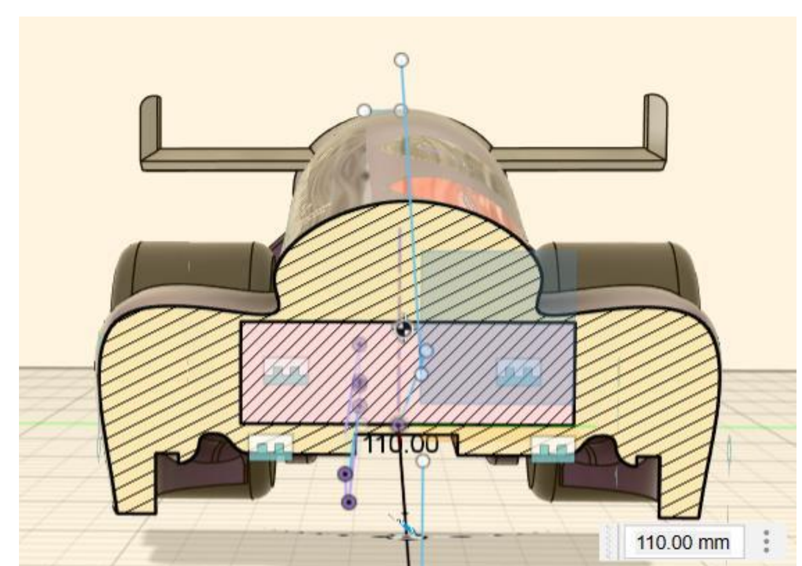
The MRC 40 router, included in the machinery used to produce the car, is also worth noting. It's equipped with a 500W spindle motor, so it can work at high speeds, and its 110mm Z-axis travel enables it to produce more intricate 3D shapes. This router is both powerful and versatile, able to perform everything from simple cutting to fine engraving and even more intricate part production. Its capacity to rapidly switch tools and be modified with additional attachments enables it to embrace a great variety of projects—not only F1 in Schools cars.

Despite not being at the helm, having an understanding of how the CNC process operates directed our design decisions. We had to consider such things as tool accessibility (so the machine would be able to reach all of the areas of the car), part thickness (to ensure that they wouldn't break while cutting), and if any area of the car would be too complex for the machine to cut correctly. That heightened our sense of design-for-manufacturing—essentially, designing not only what's aesthetically pleasing, but what's possible to actually manufacture.

Since the car was produced using CNC, we could be assured that the body would be smooth, light, and within competition tolerances. That also meant less imperfections or additional surface finishing required afterwards. Additionally, the speed and efficiency of CNC meant the car could be produced relatively quickly, which left us with more time for testing and tuning. It also meant that if we wished to re-make the car with minor design enhancements, we could do so easily, as the same digital file could simply be re-run on the machine.

Therefore, even though we weren't the ones pushing the buttons, CNC machining was a central part of our car's development. It linked the world of digital design to actual racing and made sure that our car was constructed to a high level of precision and performance. Without CNC, building a competition-worthy car that delivers consistently would be much more difficult.





Research and Development

Physics Concepts

As you can see, most of our car is rounded from the corners. This isn't for obvious reasons, since this particular shape (used in things such as plane wings) is considered the best shape for air to pass smoothly over the car.

We also looked into LERS, which helped cars to move faster, but it was banned due to safety issues. We were encouraged to see that the fastest car even without using LERS managed to complete the track in under one second. That was our goal with this car.

An important factor in determining the quality of a good F1 car is **aerodynamic efficiency**. It's the ratio of downforce to drag.

Aerodynamic Efficiency $= \frac{Downforce}{Drag}$

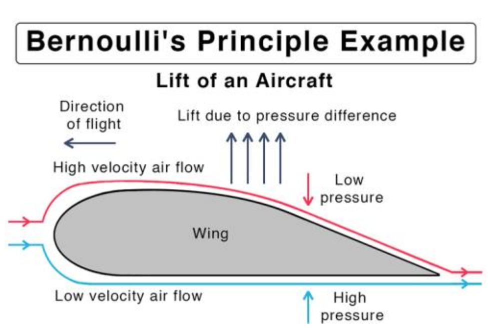
Drag $= \frac{C_d \rho A v^2}{2}$, where C_d is the drag coefficient, A is the frontal area, v^2 is the square of the velocity of the car and ρ is the density of the air around the car.

Downforce $= \frac{C_l \rho A v^2}{2}$, where C_l is the lift/downforce coefficient, A is the frontal area, v^2 is the square of the velocity of the car and ρ is the density of the air around the car.

Substituting in Aerodynamic Efficiency formula:

$$\text{Aerodynamic Efficiency} = \frac{\frac{C_l \rho A v^2}{2}}{\frac{C_d \rho A v^2}{2}} = \frac{C_l}{C_d} = \frac{Lift\ coefficent}{Drag\ coefficient}$$

This shape is considered to be the most convenient one for aerodynamics. Based on the **Bernoulli's Principle,** it states that pressure in an area is decreased when a fluid moves faster over it.



This shape would be different in cars, since lift isn't required in getting the car to move faster. This shape shows the concept of lift for aircrafts using the Bernoulli's principle.

Materials

Choosing the right materials for the car is just as important as designing it well. Even if a car looks perfect on paper, using the wrong materials could mess everything up. At high speeds, there's a lot of pressure on the car, especially on parts like the wings and wheels, and if the materials aren't strong enough or are too flexible, they could easily crack or bend. Also, if there are any small bumps or inconsistencies in the material, the airflow around the car can get disturbed. That messes with the car's aerodynamics, which can slow it down over the 20m track. Every material has certain properties—like how dense it is, how easily it melts, how much force it can handle before breaking (tensile strength), and how flexible it is. All these things matter when trying to make a car that's both fast and durable. For example, if the material is too soft or has a low melting point, it might not survive the heat and friction that comes from moving so quickly. That's especially important when it comes to the wheels. You can't have a really smooth, soft material for wheels because they'll just slide instead of gripping the track properly. That's where the coefficient of friction comes in—basically, a number that tells you how well two surfaces grip each other.

So, calculating the right amount of friction is a big part of figuring out what material to use. On top of all that, you have to think about cost. Some materials might be perfect in terms of performance, but if they're super expensive, they're just not practical. So you have to find a balance between performance and price, which is why choosing the right materials is such a big deal.

For our car, the axles are made out of nylon, which is one of the standard materials used in F1 in Schools. Nylon is stiff and strong, which is good because it means the axles won't bend or get squished under the weight of the wheels. Even though nylon can wear down over time, that's not really a problem in our case. We use ball bearings, so the wheels spin around the axles instead of the axles spinning themselves. This setup keeps the axles stable and reduces the risk of wear. Because of nylon's stiffness and durability, we also used it for the front wing. The front wing takes on a lot of pressure during the race, since it's the first part of the car that hits the air. It needs to be strong so it doesn't snap or deform. Nylon is also known to absorb moisture from the air, which could be a downside. But since the race doesn't last long and the car isn't exposed to super wet conditions, this doesn't really affect performance much.

For the rear wing, we used carbon fibre. Carbon fibre is a really strong but lightweight material, which is perfect for racing. It also tends to be smooth, which helps the air flow over it more easily, reducing drag. That's super important for maintaining speed. One of the best things about carbon fibre is that it's stiff in one direction but can flex slightly in others, which can actually help absorb some of the stress the car experiences when it launches. However, the main downside is that carbon fibre can be brittle. That means if it takes a sudden hit or too much pressure in the wrong spot, it can crack or snap instead of bending. So we had to be careful with how we designed and placed the rear wing to avoid that.

The wheels are made from PETG, which stands for Polyethylene Terephthalate Glycol-modified. PETG is a cool material because it's both tough and flexible. It's strong enough to handle the heat and stress from rolling at high speeds, but it's not so rigid that it cracks easily. One thing about PETG is that it's not perfectly smooth—it tends to have tiny surface bumps or imperfections, especially after being 3D printed. In most cases, that might be considered a bad thing, but for wheels, it's actually helpful. Those little bumps create more friction, which means better grip on the track. That extra grip helps the car launch more effectively and keeps it from sliding too much. So while PETG might not be the most polished material out there, it's a great choice for our wheels because of the extra traction it provides.

Main Scientific Principles Used In the Development of the Car

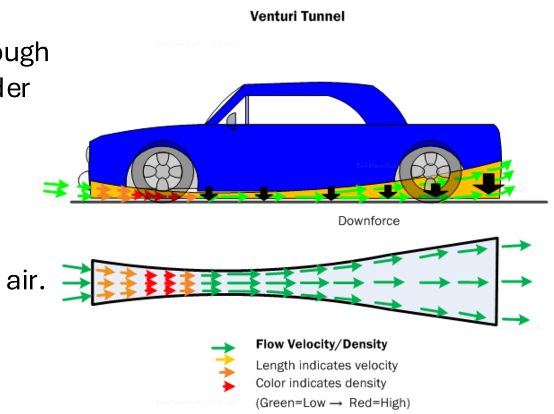
The concept of air being a fluid

A fluid comprises molecules of matter which are free to move about. The 3 states of matter *i.e. Solid, Liquid and Gas* have different ranges of the possible motion of the molecules in them. **Fluidity** is a term used to define the ability of a substance to flow. Molecules in a solid are tightly packed together and hence cannot move freely. The molecules in a liquid are less tightly packed together, but enough to keep the liquid as a body which does not disperse into the environment, whereas the molecules in air are extremely loosely packed together and the *intermolecular force* isn't strong enough to hold them together. Fluid refers to any form of matter with free-moving molecules, including both **liquids and gases**. Since air has these properties, it is also considered a fluid. The study of how objects move through a fluid is called **fluid dynamics**. To analyze motion within a fluid, principles like **Bernoulli's theorem** and **conservation laws** are used. The process of computing values such as **air velocity, pressure distribution, and turbulence** using numerical methods is called **Computational Fluid Dynamics (CFD)**. CFD allows for **simulating and visualizing fluid behavior**, making it essential in fields like **aerospace, automotive design, and engineering**.

The Venturi Effect

The Venturi Effect states that when a fluid passes through a narrow section, its speed increases. Applying Bernoulli's Principle here, the faster the air, the lesser the pressure. The pressure, therefore, decreases. This means that in a narrower section of the car, the pressure decreases since the speed of air increases.

Applying this to our car, the chassis, and the racetrack creates a small area through which air can pass. This increases the airspeed, decreasing the air pressure under the car. Now, air moves from higher-pressure areas to lower-pressure areas. This means that the air above the car pushes down to fill up the lower-pressure space, equalizing the pressure. This results in downforce. But, as speed increases, so does drag.



$F_D \propto v^2$ where F_D is the drag force and v is the velocity of the car relative to the air. Now, $F_D = \frac{1}{2}C_d A\rho v^2$ and if $F_D \propto v^2$, then $F_D = kv^2$, which means the constant of proportionality for $F_D \propto v^2 = \frac{1}{2}C_d A\rho$

The relationship between 2 cross sectional areas of pipes and the fluid's velocities in those areas is given by the continuity equation for fluid flow:

$A_1 v_1 = A_2 v_2$ where A_1 and A_2 are the cross-sectional areas of the 2 points in the 'tube' and v_1 and v_2 are the velocities of the fluid in those 2 points.

Newton's Second Law

The second law states that force is proportional to the rate of change of momentum of a body. Momentum *i.e.* $p = mv$ is the product of the mass and velocity of a body. It is the quantity of the amount of motion a body has. Momentum is a vector quantity, that means it has direction. For that reason, momentum is given as $\vec{p}$ since that is the symbol that defines a vector quantity.

It is also known as the fundamental law of motion since it cannot be derived. The equation of force *i.e.* $\vec{F} = m\vec{a}$ can be derived using this law. The law states that $\vec{F}\ \alpha\ \frac{\Delta\vec{p}}{\Delta t} = \frac{p_2 - p_1}{t_2 - t_1}$

Now, t_1 is 0, since the start is considered as 0s and Δp can be written as $mv - mu$ since $p = mv$ and u is initial velocity and v is final velocity. Also, if $a\ \alpha\ b$, then $a = kb$ where k is the constant of proportionality.

∴ This equation can be re-written as $k\left(\frac{mv-mu}{t}\right)$ and m can be substituted out; $km\left(\frac{v-u}{t}\right)$

Now, $\vec{a} = \frac{v-u}{t}$ therefore that can also be substituted. k is also normally taken as 1

$\rightarrow\ \vec{F} = m\vec{a}$

This equation is undoubtedly used everywhere when calculating force. Especially when calculating drag force and lift force to find the drag and lift coefficient.

Bernoulli's Principle

Bernoulli's Principle states that when air moves faster in an area, the pressure in that area decreases. This principle is extremely important in producing lift or downforce. This principle applies in the Venturi Effect as mentioned above. Since it's experimentally proven that air moves from higher pressure to lower pressure regions anywhere, that helps in producing force in any direction which includes lift, downforce, and drag.

The usage of Bernoulli's Principle

Bernoulli's extended equation gives us the relation between the pressure, height and velocity of 2 points in a flowing fluid (which in our case would be air).

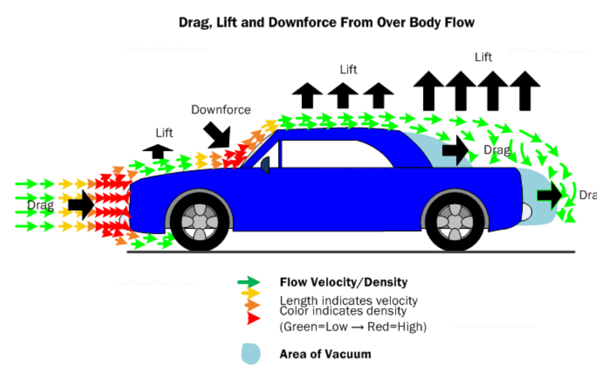
$$P_1 + \frac{\rho v_1^2}{2} + \rho g h_1 = P_2 + \frac{\rho v_2^2}{2} + \rho g h_2$$

Changing this in the form of ΔP:

$$\Delta P = P_2 - P_1 = \frac{1}{2}(\rho v_1^2 - \rho v_2^2) + (\rho g h_2 - \rho g h_1)$$

$$\rightarrow \Delta P = P_2 - P_1 = \frac{1}{2}\{\rho[\Delta(v)^2]\} + \rho g(\Delta h)$$

Normally, change in height *i.e.* $\rho g(\Delta h)$ is ignored.



Main Scientific Principles Used In the Development of the Car continued…

Newton's Action-Reaction Law

Newton famously stated that every action has an equal and opposite reaction in his 3rd law of motion. The canister exerts a force in the opposite direction of the car, and the car is pushed forward at (almost) the same force. Almost, since some of the energy is lost in real-life scenarios. But, in physics, most calculations for things like this don't account for energy loss. Rather, they use formulae which would work in an ideal world with no energy loss.

$$F_A = -F_B \rightarrow m_1 a_1 = -(m_2 a_2)$$

The car exerts a force on the ground based on the Venturi Principle and the ground exerts an equal force on the car. This way, the car does not sink into the ground.

Aerodynamic Efficiency

There isn't really a specific number which is considered "good" for aerodynamic efficiency. It depends upon the nature of the track. But in actual Formula 1, If a track has more straights, then there would be lower downforce, and the efficiency would be higher, around 5 to 6

But if the track has more turns, downforce is crucial for maintaining the stability of the car. Therefore, efficiency would be lower, around 2 to 3.

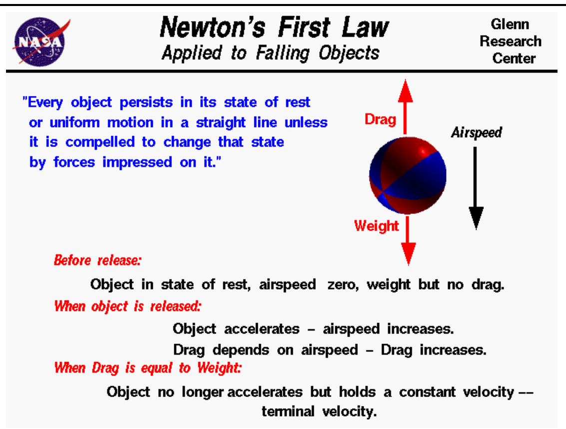
The reason why aerodynamic efficiency becomes higher with lower downforce is because the drag decreases as well, therefore the ratio doesn't change according to only the downforce parameter.

In our case, the track is completely straight. This means that the required downforce is reduced, since extra downforce is mostly required for stability while taking fast turns.

Even on straights, F1 cars change the angle of their rear wing to be almost parallel to the ground since the downforce created by the angle of the rear wing isn't really required. Since our car is much lighter than regular F1 cars, the ratio will be much lower, where it may be between 0 and 1.

Based on the values of our simulations, we noticed that the aerodynamic efficiency of our car is around 0.5, which is optimum for good performance.

Application of Inertia



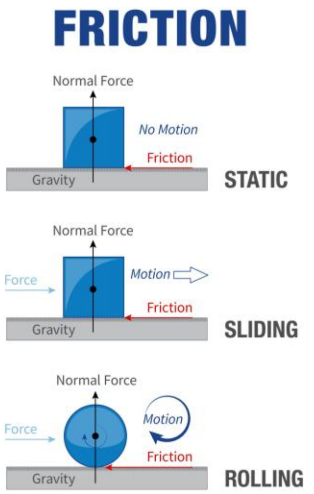
The inertia of a moving body is its tendency to stay in motion, that of a still body is its tendency to stay stationary and that of a rotating body is its tendency to stay in rotation. These are the 3 types of inertia as defined by Newton's first law also known as the law of inertia *i.e. Inertia of rest, inertia of motion and inertia of direction*. "An object in motion will stay in motion unless a **net** external force is applied on it." Inertia or I is calculated using the mass or m. $I = m$, therefore $I \alpha m$ where $k = 1$. If an object has lesser inertia *i.e. tendency to stay in (in this case) motion,* the object can accelerate and break faster, therefore having lesser mass means the car can accelerate faster which is an advantage. With that, comes an increase in the requirement of friction in the wheels.

The Friction Coefficient

The Friction Coefficient, or μ, is extremely important in determining the amount of friction required to help make sure that the car moves smoothly and does not skid.

$$\mu \geq \frac{a}{g}, F = ma \rightarrow a = \frac{F}{m} \rightarrow \mu \geq \frac{F}{mg} m \rightarrow \mu \geq \frac{F}{W}$$

F (thrust) exerted by CO_2 canister $= \dot{m}v_e + A_e(P_E - P_A)$ where $\dot{m}$ is the mass flow rate and v_e is the exit velocity, A_e is the area of the nozzle's exit area and P_E, P_A are the pressures inside the canister and the atmospheric pressures respectively.



Materials	μ_s	μ_k
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Copper on steel	0.53	0.36
Rubber on concrete (dry)	1.0	0.8
Rubber on concrete (wet)	0.3	0.25
Wood on wood	0.25-0.5	0.2
Glass on glass	0.94	0.4
Teflon on Teflon	0.04	0.04
Teflon on steel	0.04	0.04
Waxed wood on wet snow	0.14	0.1
Waxed wood on dry snow	0.10	0.04
Metal on metal (lubricated)	0.15	0.06
Ice on ice	0.1	0.03
Synovial joints in humans	0.01	0.003
Very rough surfaces		1.5

Testing

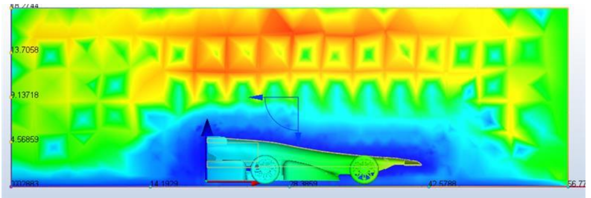


Figure A

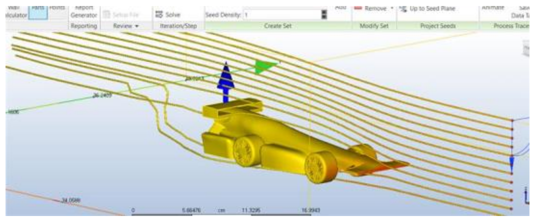


Figure D

We ran a quick CFD simulation, and this is what we found:

Fig. A illustrates the pressure distribution around the car. The green regions along the car's surface indicate stable pressure zones, suggesting that there is no significant accumulation of excess pressure that could hinder the car's aerodynamic efficiency. At the rear of the car, the blue region signifies wake, a form of pressure drag that occurs when airflow separates after an abrupt tapering. Wake contributes to aerodynamic drag and can reduce the car's speed.

Due to the design constraints, we were limited in how much we could alter the rear tapering. As a result, we proceeded with CFD (Computational Fluid Dynamics) simulations and allowed all iterations to run to completion. Upon analyzing the results, particularly in Fig. F and Fig. B, we observed minimal wake formation at the back of the car. This is a positive outcome, as it implies reduced drag forces that would otherwise slow the vehicle down.

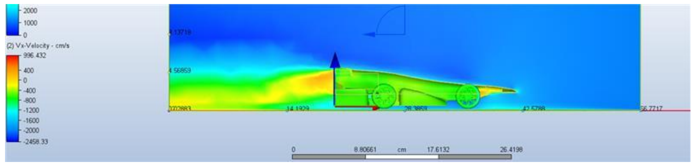


Figure F

Figure C

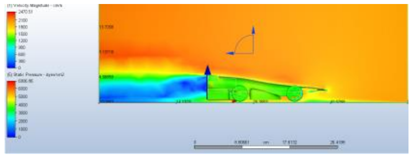


Figure B

Additionally, Fig. B presents the velocity magnitude simulation of airflow around the car. Velocity magnitude refers to the speed of the fluid at each point in the flow field, regardless of direction. This visualization helps us better understand how the air behaves as it moves over and around the car's surfaces.

It is given by:.

$|\vec{v}| = \sqrt{u^2 + v^2 + w^2}$ where u, v, w are velocity points in 3D space.

The blue areas represent slower-moving air, while the red areas indicate regions of higher airspeed. During the manufacturing process, the nosecone slot was not fabricated correctly, which resulted in the nosecone being mounted with a slight downward tilt, as shown in Fig. C. Interestingly, this imperfection may have had a positive aerodynamic effect.

Fig. B shows that air moved slightly slower under the nosecone than above it. This could've caused a bit of lift at the front, but the nosecone's downward angle (shown in Fig. C) likely helped guide the airflow better, adding to the car's performance.

During testing, the car ran consistently well. All runs were under 1.5 seconds, with the fastest at 1.2 seconds. This showed the design was effective and reliable.

Fig. E shows a used CO_2 canister. We made sure each one worked properly to keep launches consistent.

Overall, the test day confirmed that our design and simulations were accurate. It also showed how important good building, quality checks, and quick problem-solving are.

In the CFD results:

X-velocity (XVel) indicates how fast the air is moving in the direction of the car. Higher values in this direction mean the car is maintaining its speed efficiently, with less drag slowing it down.

Y-velocity (YVel) shows the airflow moving from side to side. Low values of Y-velocity are ideal because they suggest minimal lateral airflow, which helps reduce turbulence and drag, contributing to better stability.

Z-velocity (ZVel) represents vertical airflow. Negative values here suggest that the air is flowing downward, which is critical for generating downforce and keeping the car glued to the track, enhancing stability and control.

Pressure (P) indicates the air pressure at different points. Low-pressure areas (where air accelerates) lead to downforce, while high-pressure zones (where air slows) can create drag. Understanding pressure distribution helps us improve car handling and reduce drag.

Turbulence (Turb) reflects the chaotic movement of the air. Low turbulence values are desired because they mean the airflow is smooth, which results in lower drag and better aerodynamic efficiency.

Temperature (T) measures the temperature of the air. Cooler air is denser and offers more lift, which can affect the car's aerodynamic performance. The air temperature influences the air density, and denser air provides better performance.

Iteration	Vx Vel	Vy Vel	Vz Vel	Pressure	Temp	TKE	TED
310	-382.573	-0.812288	-0.478061	3853.38	0	8923.83	1.11E+10
311	-383.081	-0.805025	-0.517127	3852.09	0	8940.19	1.11E+10
312	-383.586	-0.79818	-0.555392	3850.8	0	8956.58	1.11E+10
313	-384.089	-0.791727	-0.592843	3849.53	0	8972.77	1.11E+10
314	-384.589	-0.785609	-0.629572	3848.26	0	8988.85	1.11E+10
315	-385.086	-0.779835	-0.665436	3847.01	0	9004.71	1.11E+10
316	-385.581	-0.774407	-0.700543	3845.76	0	9020.52	1.11E+10
317	-386.074	-0.769394	-0.73495	3844.52	0	9036.16	1.11E+10
318	-386.563	-0.764793	-0.768597	3843.29	0	9051.69	1.11E+10
319	-387.05	-0.760584	-0.801529	3842.07	0	9067.01	1.11E+10
320	-387.535	-0.756802	-0.833792	3840.86	0	9082.33	1.11E+10
321	-388.016	-0.75342	-0.865425	3839.65	0	9097.37	1.11E+10
322	-388.496	-0.750401	-0.896399	3838.45	0	9112.47	1.11E+10
323	-388.972	-0.747748	-0.926785	3837.27	0	9127.21	1.11E+10
324	-389.446	-0.745471	-0.956598	3836.08	0	9142.01	1.11E+10
325	-389.918	-0.743611	-0.985806	3834.91	0	9156.54	1.11E+10
326	-390.387	-0.742087	-1.01449	3833.74	0	9171.06	1.11E+10
327	-390.853	-0.740945	-1.04266	3832.59	0	9185.31	1.11E+10
328	-391.317	-0.740187	-1.07033	3831.44	0	9199.57	1.11E+10
329	-391.778	-0.739878	-1.09755	3830.29	0	9213.58	1.11E+10
330	-392.236	-0.739881	-1.12432	3829.16	0	9227.6	1.11E+10
331	-392.692	-0.740216	-1.1506	3828.03	0	9241.35	1.11E+10
332	-393.145	-0.740881	-1.17651	3826.91	0	9255.05	1.11E+10
333	-393.596	-0.74193	-1.20202	3825.79	0	9268.63	1.11E+10
334	-394.045	-0.743348	-1.22719	3824.69	0	9282.05	1.11E+10
335	-394.49	-0.745029	-1.25201	3823.59	0	9295.28	1.11E+10
336	-394.934	-0.747002	-1.27647	3822.49	0	9308.55	1.11E+10
337	-395.374	-0.749285	-1.30065	3821.41	0	9321.57	1.11E+10
338	-395.812	-0.751831	-1.32449	3820.33	0	9334.59	1.11E+10
339	-396.248	-0.754646	-1.34808	3819.25	0	9347.33	1.11E+10
340	-396.681	-0.757712	-1.3714	3818.19	0	9360.04	1.11E+10
341	-397.111	-0.761046	-1.39454	3817.13	0	9372.58	1.11E+10
342	-397.539	-0.764624	-1.41749	3816.07	0	9385.1	1.11E+10
343	-397.965	-0.768446	-1.44022	3815.02	0	9397.36	1.11E+10
344	-398.388	-0.772458	-1.4628	3813.98	0	9409.67	1.11E+10
345	-398.808	-0.776651	-1.4852	3812.95	0	9421.82	1.11E+10
346	-399.226	-0.780993	-1.5074	3811.92	0	9433.95	1.11E+10
347	-399.642	-0.785532	-1.52947	3810.9	0	9445.77	1.11E+10
348	-400.055	-0.790315	-1.5514	3809.88	0	9457.63	1.11E+10
349	-400.466	-0.79527	-1.57318	3808.87	0	9469.26	1.11E+10
350	-400.874	-0.80039	-1.59485	3807.87	0	9480.91	1.11E+10
351	-401.28	-0.805615	-1.6164	3806.87	0	9492.32	1.11E+10
352	-401.684	-0.810943	-1.63782	3805.88	0	9503.68	1.11E+10
353	-402.085	-0.816412	-1.65915	3804.89	0	9514.85	1.11E+10
354	-402.484	-0.821965	-1.68034	3803.91	0	9526.01	1.11E+10
355	-402.88	-0.827615	-1.70142	3802.94	0	9536.96	1.11E+10
356	-403.274	-0.833352	-1.72239	3801.97	0	9547.92	1.11E+10

Example of Iterations' data run

Figure E

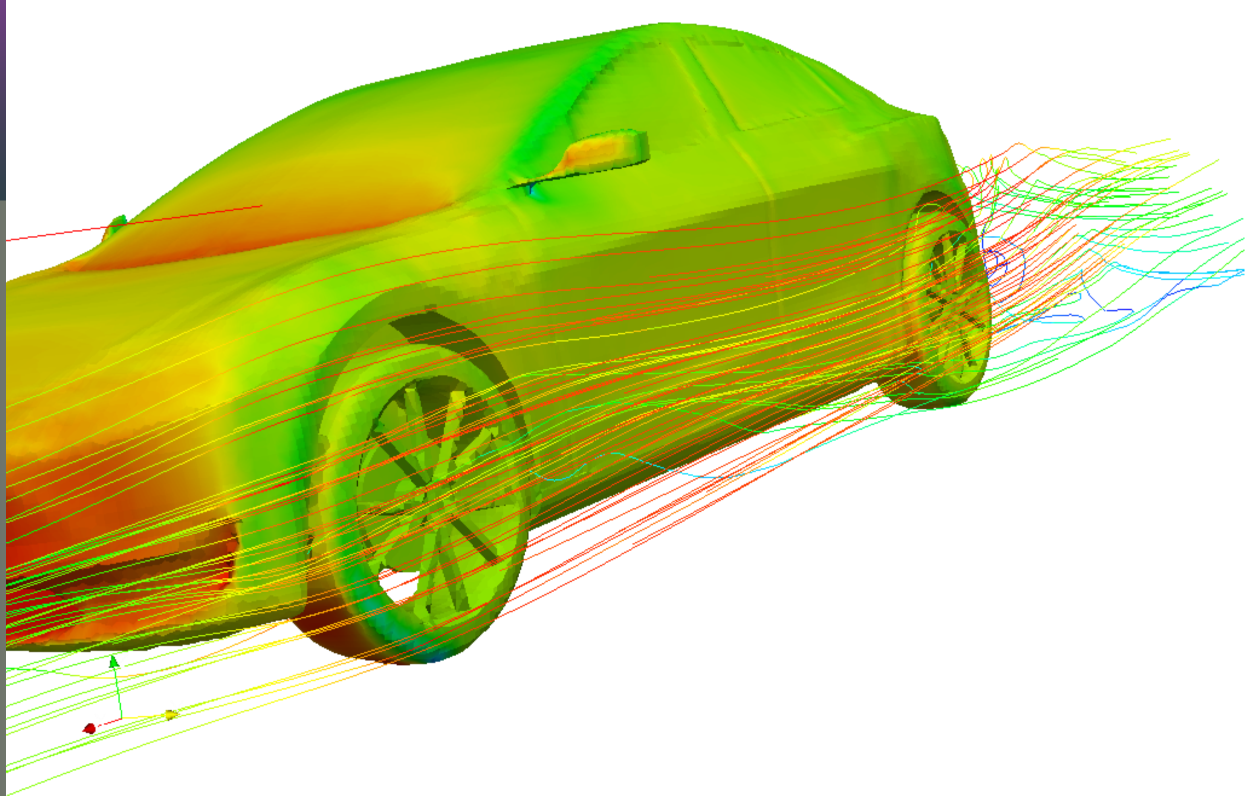
Effect of Wheels on Car Aerodynamics

Wheel design is critical in many respects for aerodynamic properties for F1 in Schools. While racing cars are small, they still utilize many of the principles associated with larger cars. Wheels contribute to drag and turbulence as wheels spin and are exposed to the elements, making them relative features of slow-downs.

If wheels are not designed properly, or there is too much space from wheels to the body, airflow separation occurs which promotes greater pressure drag that will decrease vehicle speed. The air that encounters the wheel wells or the wheels themselves create vortices which can unsettle the overall aerodynamic quality of the vehicle.

We tried to resolve this with lightweight, low-friction wheels with rounded edges, including wheel surrounds which are fitted to reduce as much exposure as possible. In extreme instances, teams have crafted their bodies to assist with airflow around the wheels to a better advantage.

Every millisecond matters in racing and adjustments to wheel design can go a long way in performance. Wheel placement, design, and accessories that surround them are essential for both speed of acceleration and the best aerodynamics



1.Drag Created By Wheel Spinning
Even though F1 in Schools cars are small, they race with their wheels spinning at incredibly high RPMs. This creates additional drag via turbulence from the spinning wheels. The wheels disrupt the ideal airflow moving over and around the car's body and thus create unorderly air patterns. This is known as rotational/induced drag and, if proportioned, this could create an immense problem to slow down the car.
For a real-life Formula 1 car, open wheels are created as one of the least favorable features of aerodynamics. So in F1 in Schools, if wheels are exposed—exponentially worse if they are not shaped well—they create energy waste and inefficiency.

2.Wheel Dimensions and Cross-Section
The thickness and diameter of the wheels influence how air reacts to them. Larger wheels will chop through more air and offer additional frontal area to the car, which encourages form drag. At the same time, thicker wheels will create broader disruptions in the air as well as larger wakes behind them, which require higher pressure drag.
F1 in Schools teams at times, implement low-friction axles to allow wheels to spin more easily. The less force that is needed to turn a wheel, the lower the friction it is, allowing the car to go further. However, there is always a trade-off with low-friction axles, especially if they are constructed with softer materials that wear down more. In addition, poorly aligned wheels will prevent the axle from turning properly. Therefore, stability versus speed is always taken into consideration.
Although not genuinely aerodynamically linked, wheel alignment and drag explain how wheels turn and how air subsequently flows. For instance, misaligned wheels can turn on a slant, creating yaw, where the car does not travel in a perfectly straight direction. Thus, an errant air pattern occurs, creating more aero instability.

3. Material and Surface Finish
The wheel surface texture impacts how air engages with the wheel. A textured or uneven wheel surface increases skin friction drag—when air moves across any material and drags behind it due to properties that increase drag. That's why, in F1 in Schools, some teams polish their wheels or paint them to reduce any additional drag and to maintain a laminar flow over and surrounding the spinning wheels.
Also, the material for wheels should be as light as possible, such as carbon-reinforced nylon or molded polymers, because this minimizes rotating moments and minimizes the energy required to get the wheels spinning. Less energy lost via the wheels means more energy available for propulsion via the CO_2 cartridge.

4. Front vs Rear Wheel Design
The front wheels of an F1 in Schools car create more drag than the rear wheels. The front wheels are more exposed and if they aren't properly faired or blended, they create turbulence in the air moving toward the rear which can disrupt downstream aerodynamics.
Some of the more veteran teams have used asymmetric wheel fairings where the fairing on the side due to the front wheel is more steeply tapered or enclosed and on the rear side it's more open to allow air to more easily escape. This keeps flow continuity from front to back.

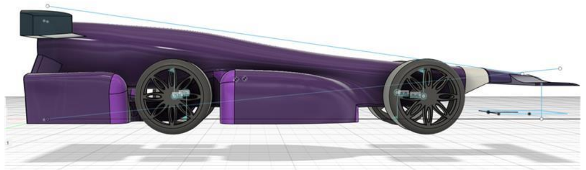
5. Testing and Optimization
A lot of the F1 in Schools teams that are more professional utilize virtual wind tunnel testing (CFD - Computational Fluid Dynamics) to see what manner of wheels work best. Students can see airflow around the wheels along with the pockets of high pressure or turbulence.
In addition, track testing with timing gates allows teams to empirically support their design choices as they relate to wheels. Even the most minuscule adjustments—millimeters larger or smaller in width, the most slight variation in curvature of the fairing—can create time differences on the track.

6. Innovative Approaches
A few teams have created alternative wheels such as:
•Knife-edge wheels so there's no surface area on the sides,
•Reduced spokes to reduce drag on the inside surface,
•Vented wheels to prevent pressure from building behind the wheel.
Not every experimental design will work, though. F1 in Schools has a creative component; thus, new ideas for how to aerodynamically better a wheel could give a leg up on the competition.

Car Design

The Car went through many design iterations until we came to this one. As mentioned before, the car's design was inspired by the hammerhead shark. A lot of the unnecessary weight was dropped by emptying out the bottom of the car. The center of mass is towards the back, below the vertical center of the car. This means that there's more weight towards the bottom and the back of the car which helps in stability. The front is kept light since the car is moving completely straight and no turning is accounted for, other than the slight turning the car might experience due to drag on the straight track (we've done our best to make sure that that doesn't happen).

- Front wing is made using Nylon
- Rear wings are made using Nylon
- Axles are made using Carbon Fibre
- Wheels are made using PETG



Our Wheel Design

Our current car has a special type of wheel and axle structure. The axle hole doesn't go fully through, and instead, each wheel has a small axle of its own, which is connected to the wheel through a ball bearing of size 4mm x 9mm x 4mm. The front of our car has a special slot made for the nosecone to fit into. The back of the car also has a slot which the rear wing can slide into. Both of these parts had some level of manufacturing defects so the had to be made by hand.

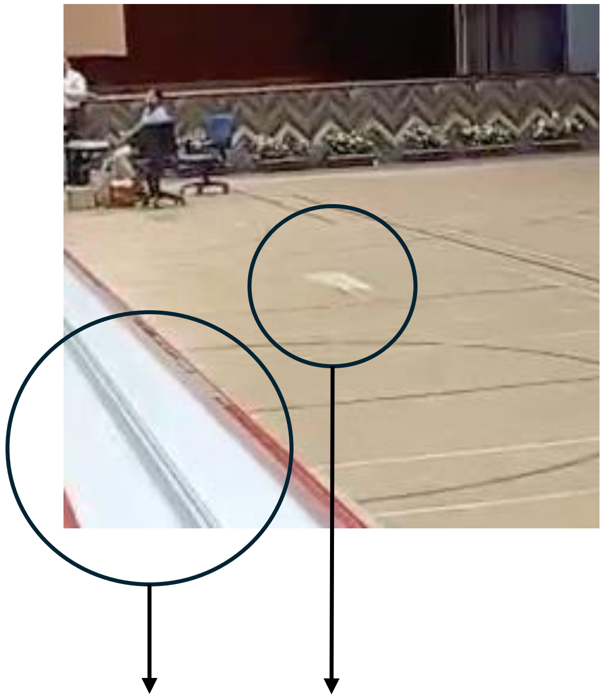
The rear wing design was originally slightly different. There wasn't a connection on the top, so the rear wing looked slightly different.

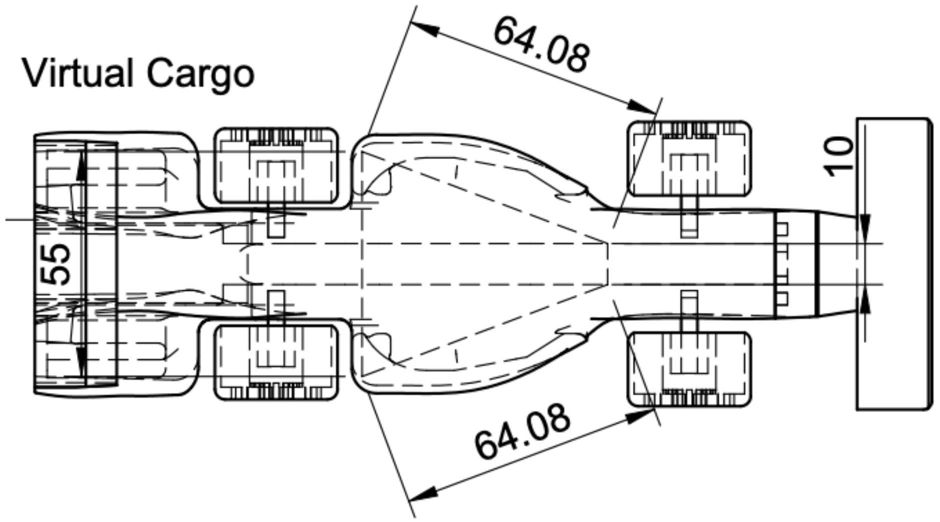
When we received the car, we immediately noticed a few critical design flaws.

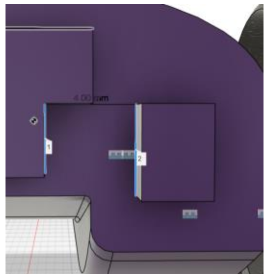
- The axle holes weren't cut
- The depth of the cavity required to slot the rear wing into wasn't enough
- The nosecone's connection joint could not be manufactured cleanly by the CNC machine

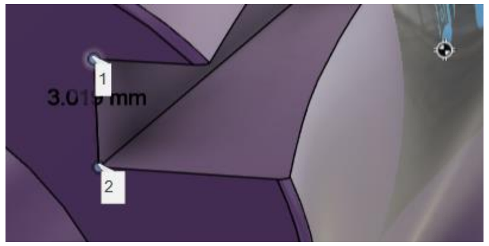
We were eventually able to resolve these issues. Initially, we hadn't anticipated that the drill bit would struggle with certain cuts, so many of the problems had to be corrected manually. Due to the unique circumstances and the large diameter of the axle holes, those could not be machined as intended either.
During one of the testing sessions, the car unexpectedly detached from the tether line without actually snapping it and flewoff the track.
We suspect this was due to the left axle not being properly secured with adhesive. However, this still does not fully explain how the car came off the tether line while both hooks remained intact. We jokingly remarked that "the atoms must have aligned" to let the hooks slip free without breaking the tether, though the situation was genuinely concerning.

Fortunately, the car was not seriously damaged. After making the necessary repairs, we conducted multiple re-tests, and the issue did not occur again.









The Track

The Car

REAR WING

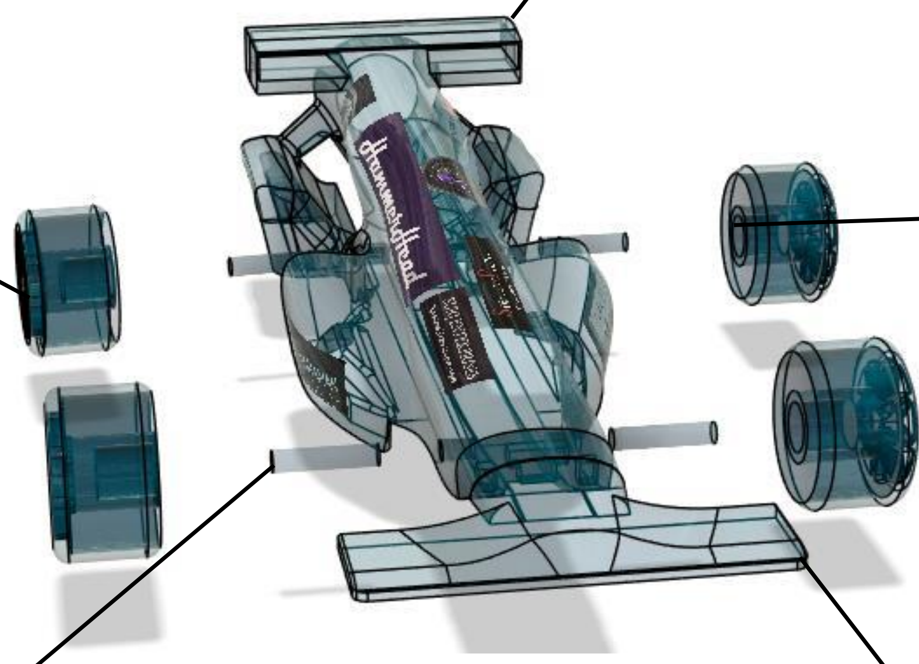
The rear wing has an interesting feature- it's parallel to the ground (except a small curve on the connector at the top), since lesser downforce is required for a straight track.

WHEELS

The wheels on our car have a special spoke-like design to reduce weight by reducing material and eliminating the need for wheel caps

BEARING SLOTS

The wheels have a slot of diameter 9mm which allows one to slot in a ball bearing which has an inner diameter of 4mm, which is the exact inner diameter of the axles.



AXLES

The axles have a special design, they don't go completely through. Rather, they stay rigid, allowing for wheel movement using ball bearings.

NOSECONE

The nosecone is thin from the front which allows air to cut through the air cleanly without leaving too much of pressure difference, while also being a slick design, looking like a HammerHead shark