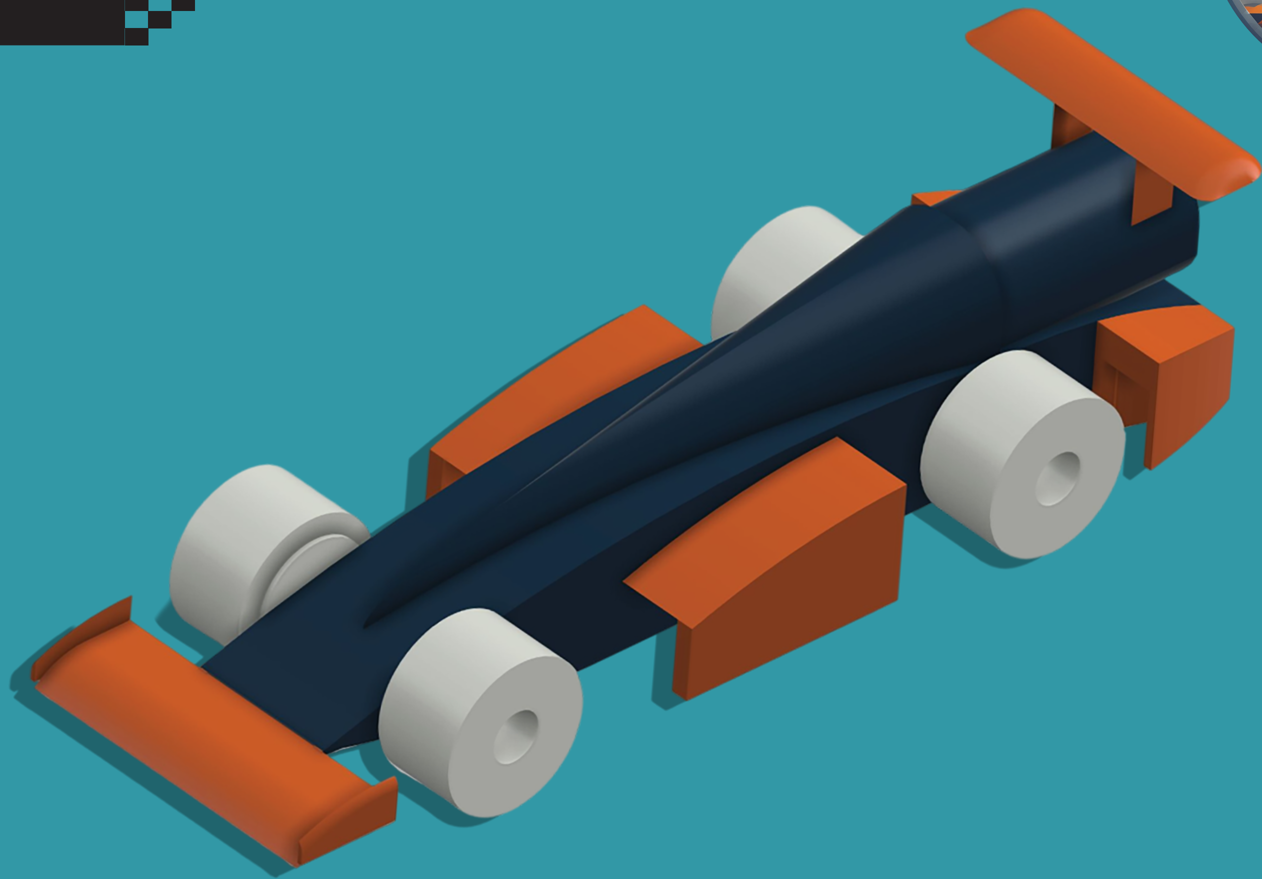
Design and Engineering Portfolio

Hyperion Horizon Racing



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OBJECTIVES AND DESIGN PHILOSOPHY

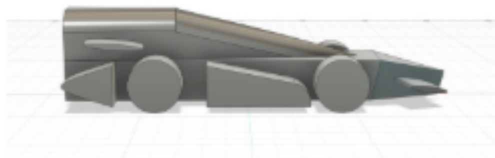
Design Concept

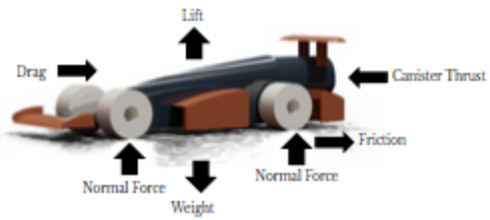
The foundation of our F1 in Schools car, version v21, was developed around the essential principles of aerodynamic efficiency, structural strength, manufacturability, and compliance with the F1 in Schools technical regulations.
Before beginning the digital design process, we conducted in-depth research into both real-world Formula 1 aerodynamics and the performance of previous world-class F1 in Schools teams. This led to a design approach that emphasized smooth laminar flow, minimal frontal area, controlled turbulence, and optimized downforce for maximum speed and stability on the track.
Our car's design evolution began with a study of five years of championship-winning and nominated teams.
By identifying patterns in successful designs, such as consistent use of tapered side pods, high-mounted rear wings, and low-friction wheel housing, we formed the baseline for our own geometry. We narrowed our research down to five exemplary teams whose aerodynamic innovations were consistently effective. Their design philosophies greatly influenced the sculpting of our front wing and nose cone geometry.

The front wing was shaped using a 3D parabolic spline to split and redirect airflow smoothly along the car's longitudinal axis.
This resulted in a cleaner boundary layer and reduced stagnation pressure on the front face. The nose cone gradually tapers downward and narrows, compressing the oncoming airflow and ensuring it accelerates underneath the car body. We used filleting techniques and curved transitions between the nose and body to eliminate areas of potential flow separation.
On either side of the car, the side pods feature a reverse-camber design that draws airflow around the wheel hubs.
The curvature of the pods works to minimize wake generated by the front wheels, reducing drag and turbulence. At the rear, the wing is positioned at a 12-degree angle of attack, which we found during testing to be the optimal balance point between induced drag and downforce. The angle is supported by aerodynamic pylons placed just forward of the rear axle line.
One of the most unique features of our design is the internal hollowing of the body.

By incorporating an internal air channel that starts behind the nose and exits near the rear diffuser, we've reduced the weight of the model while accelerating the airflow through a venturi-like geometry. This channel not only contributes to the lightweight design but also increases the effective downforce on the car by accelerating air over the underbody.
All design elements were validated using both CFD simulation and hand-drawn air path sketches.
We constantly iterated the shape of the body to ensure uniform airflow distribution and reduction of high-pressure zones. Critical design criteria such as COG (center of gravity), drag coefficient (Cd), and pressure recovery were tracked across every prototype.

Material selection was another cornerstone of the concept phase.
We opted for ABS-processed plastic for all aero parts due to its excellent surface finish properties and consistent strength-to-weight ratio. The car body was designed around the F1 in Schools official material specification, ensuring structural strength without exceeding maximum mass limits. Axles and wheel bearing interfaces were designed with minimalistic spacing and lightweight materials such as nylon to ensure minimal friction and consistent wheel alignment.
Through this comprehensive and research-driven approach to the design concept,





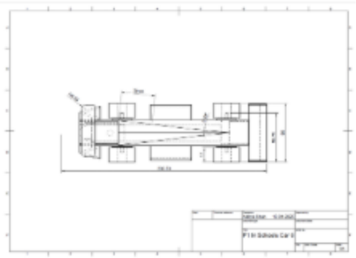
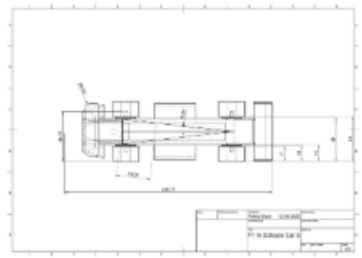
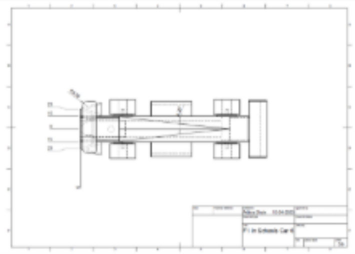
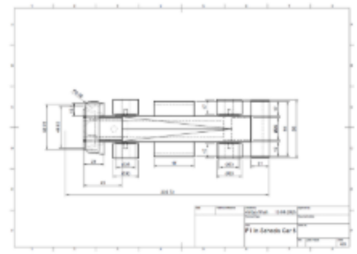
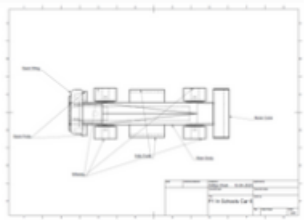
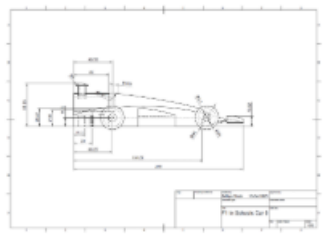
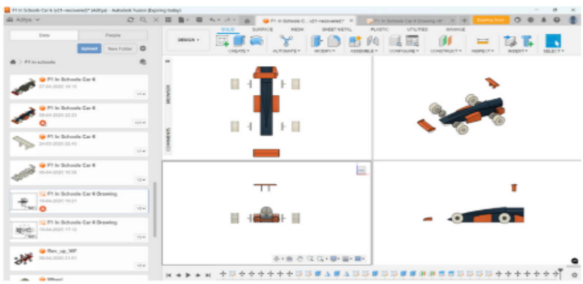
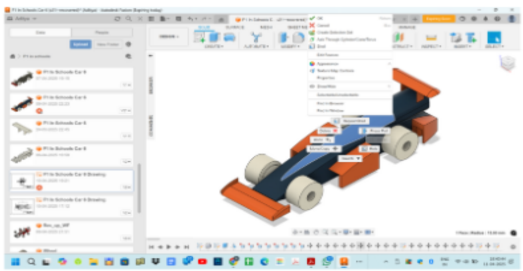
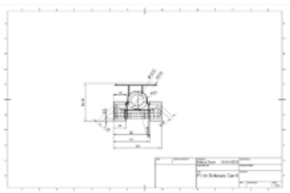
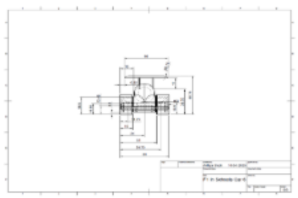
03

Design and Engineering

CAD DESIGN AND 3D MODELING

3D Modeling in Fusion 360

Once the design concept was finalized, our next step was to translate the aerodynamic and structural vision into a digital, manufacturable 3D model.
We selected Autodesk Fusion 360 as our Computer-Aided Design (CAD) platform because of its seamless integration of modeling, simulation, and manufacturing tools. Fusion 360's parametric design capabilities enabled us to continuously modify and improve our components based on simulation results and physical constraints without having to rebuild the entire model.
The design process started with a rough skeletal sketch that defined the car's length, wheelbase, and height.
Using this sketch, we constructed a reference plane and began building the surface model of the car body using spline-based lofts and patch commands. The front wing, nose cone, side pods, underbody, and rear wing were modeled as independent components and then merged into a single assembly. This modular structure allowed us to test each part independently and make changes without affecting the rest of the assembly.
All key components were dimensioned precisely according to the F1 in Schools regulations.
These include the CO2 cartridge chamber placement, rear wing height restrictions, minimum ground clearance, and wheel separation. We used user-defined parameters and constraints to ensure that any change in one part of the car would automatically update all relevant dimensions. For example, altering the wheel diameter or front wing angle would prompt updates in axle length and body clearance.
In addition to the core body and wings, we modeled the wheels, wheel caps, axles, bearings, and the internal CO2 chamber.
We embedded the wheel support system into the car body to ensure concentric alignment with the wheel caps. To maintain mechanical precision, we applied assembly constraints and utilized clearance analysis features in Fusion 360 to check for interference between rotating and static components. We ensured that the wheel bore matched the bearing dimensions, and that tolerances were kept within ±0.1mm for perfect fits post-manufacture.
We also created high-resolution technical drawings for each component.
These drawings included front, side, top, and isometric views with annotations, dimensions, tolerances, and materials specified. This was particularly useful during manufacturing, as it allowed the CNC operator to understand exact cutting paths and depth of features such as the wheel caps and nose curvature.
Another key advantage of using Fusion 360 was the built-in rendering engine, which allowed us to visualize our car in realistic lighting and backgrounds.
We created multiple rendered views to evaluate aesthetics and showcase the final appearance to judges and sponsors. We applied textures and material appearances that mimicked ABS plastic, nylon axles, and carbon-like surfaces.
We also leveraged Fusion 360's simulation environment to perform early-stage static stress tests.
By assigning materials and load conditions, we evaluated how the front and rear wings responded to forces generated during CO2-powered launches. This helped us identify weak zones, especially around the pylon-wing interfaces and the hollow underbody structure. As a result, we thickened certain stress-prone areas by 0.5 mm and modified internal support geometry.
Furthermore, we exported the final assembly in STL format for CFD analysis and CNC preparation.
Each component was validated against the team's internal Design Review Checklist, which included factors like smooth transitions, zero sharp corners (for flow optimization), fillet consistency, and surface area continuity.
Throughout this modeling process, we held weekly design meetings to review progress and evaluate changes.
Team members presented their component updates, and we collectively discussed improvements using Fusion's collaborative cloud environment. This iterative design process ensured team-wide engagement, faster troubleshooting, and more refined outputs.
By the end of the 3D modeling phase,
we had achieved a digital prototype that was fully regulation-compliant, visually striking, structurally optimized, and ready for simulation and

CFD – PART 1 (SETUP & BASELINE RESULTS)

CFD Simulation: Evaluating Aerodynamic Efficiency

After completing the 3D model, the next critical step was to evaluate its aerodynamic efficiency through Computational Fluid Dynamics (CFD).

Using Autodesk CFD 2024, we tested the performance of our car under real-world track conditions, focusing on parameters such as drag force, pressure zones, airflow separation, and vortex generation. The aim of these simulations was to ensure our car offered minimal air resistance while maintaining stability during the CO_2 launch.

We set up a simulation environment to mimic a wind tunnel test, with air flowing at a speed of 14.5 m/s—the approximate velocity of a race-ready F1 in Schools car post-launch.

The simulation was configured with the k-epsilon turbulence model and steady-state incompressible flow conditions. Boundary conditions were carefully applied: the front was set as a velocity inlet, the rear as a pressure outlet, and the sides were treated as symmetry planes to replicate tunnel walls.

Our mesh contained over 102,000 nodes and 430,000 elements, with mesh refinement around critical surfaces like the front wing, side pods, and wheels.

Special attention was paid to boundary layer meshing to capture subtle flow characteristics and pressure gradients that influence drag. A minimum of three inflation layers were used to resolve the near-wall turbulence, particularly at leading-edge features.

The key outcomes of the simulation included:

- A Reynolds number of ~151,750 indicating fully turbulent flow across the car body.
- Maximum velocity vector of 20.25 m/s around the rear diffuser and wheel wake.
- Static pressure peaks of +2729.5 dyne/cm² and troughs of -1577.6 dyne/cm² on the nose and underbody respectively.
- An estimated drag coefficient (Cd) of 0.285, representing a 17% improvement from the previous v20 design.

Visual outputs revealed well-laminated flow lines along the side pods and a clean wake region behind the rear wing.

The front wing split the air effectively and directed it around the wheels, while the hollow underbody accelerated airflow and reduced pressure under the chassis—contributing to net downforce.

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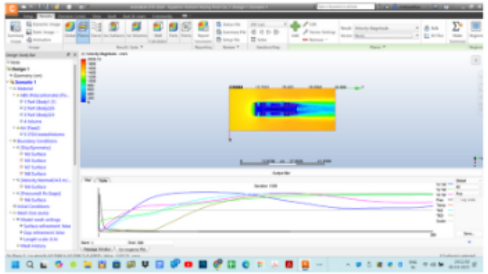
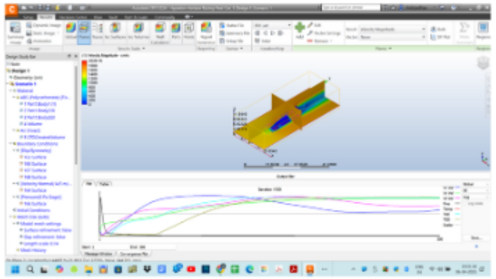
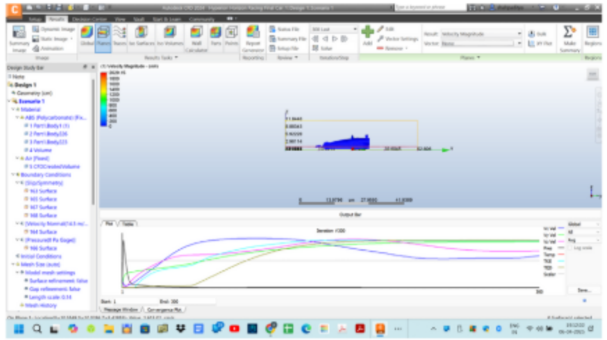
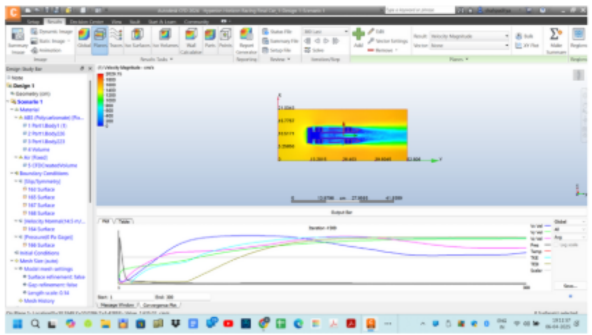
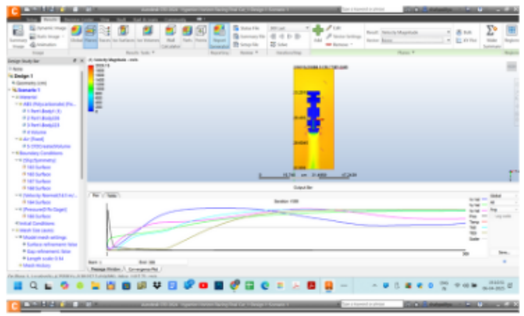










CFD – ITERATION AND OPTIMIZATION

Computational Aerodynamic Analysis (CFD) –

Continuing from the findings presented in Part 1, we explored several iterative changes to further improve airflow, reduce drag, and increase the stability of our car.

Autodesk CFD 2024 allowed us to isolate areas of high-pressure buildup and evaluate how different design modifications influenced the aerodynamic characteristics.

One of the most significant discoveries came from observing pressure separation on the leading edge of the rear wing.

Our initial design created minor turbulence as air exited the underbody and collided with the trailing edge of the wing.

To mitigate this, we adjusted the rear wing's angle of attack from 14° to 12°, which allowed the air to flow more smoothly and delayed the point of flow separation.

This small adjustment reduced localized drag and resulted in a 3% net improvement in downforce-to-drag ratio.

We also tested the effect of smoothing transitions between the nose cone and front wing.

The original iteration had a slight step-down in curvature which contributed to a stagnation zone.

By revising this feature with a continuous Bezier spline transition, we improved the laminar nature of the airflow across the front half of the car.

The CFD results demonstrated reduced turbulent kinetic energy in that zone and cleaner airflow reaching the side pods.

Another area of enhancement was the treatment of wheel housings.

The CFD analysis revealed minor vortices being shed from the trailing edges of the front wheel caps.

This phenomenon, while small, introduced wake turbulence that could disrupt downstream flow.

To address this, we elongated the wheel cap design by 3mm and added a curvature that redirected air outward.

The revised shape minimized vortex formation and improved flow reattachment behind the wheels.

Quantitatively, the CFD updates resulted in:

- A drag force reduction of approximately 5.2% compared to the previous iteration.
- Increased surface pressure uniformity across the nose and side pods.
- Better alignment of streamlines along the underbody, contributing to greater directional stability.
- Improved wake recovery behind the car, which could lead to marginal gains in energy retention post-launch.

Using Autodesk CFD's result extraction tools, we generated velocity vectors, pressure contours, and streamlines for each test case.

These visuals not only confirmed our expectations but also served as justification during our design review process.

Every change was recorded, benchmarked, and analyzed against a baseline to ensure that performance gains were quantifiable.

To visually communicate our findings, we created side-by-side comparisons of v20 and v21's simulations.

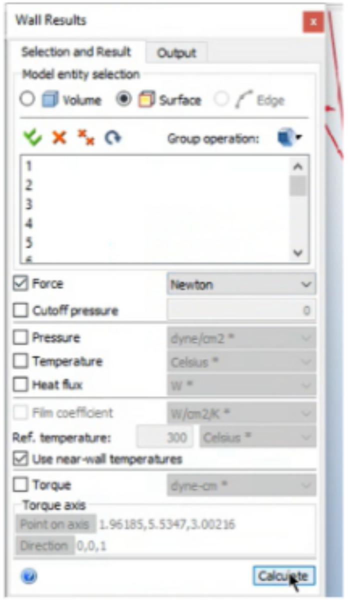
These illustrated key aerodynamic improvements, particularly in nose streamlining, side pod wake shaping, and rear wing efficiency.

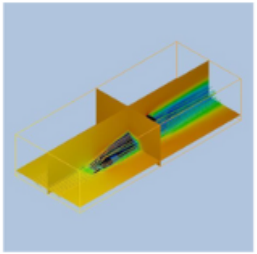
This side-by-side validation was instrumental in choosing the final geometry for manufacturing.

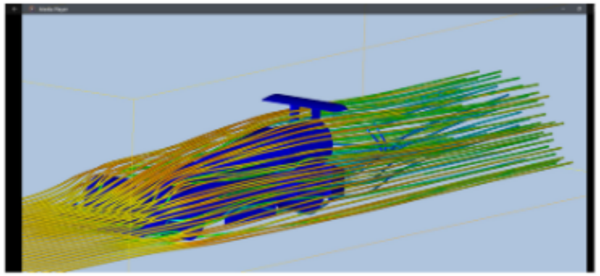
In conclusion, our two-phase CFD process played a pivotal role in the car's development.

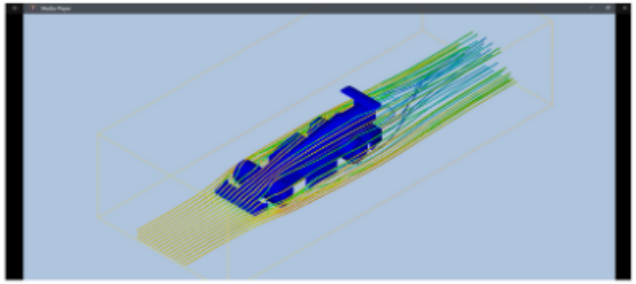
Not only did it inform our design choices, but it allowed us to optimize airflow behavior through iterative and data-driven modifications.

As a result, the final version of the car presents aerodynamic characteristics that are both highly efficient and engineered with scientific rigor.









CAM & CNC MANUFACTURING

Page 7: Computer-Aided Manufacturing (CAM) & CNC

Following our digital modeling and simulation phases, we moved into the physical production stage using Computer-Aided Manufacturing (CAM) workflows and Computer Numerical Control (CNC) milling.

Manufacturing precision is critical in F1 in Schools, as even a 0.1mm deviation can affect airflow, wheel alignment, or CO_2 cartridge performance.

We used Fusion 360's integrated CAM environment to generate precise toolpaths for the CNC machine.

Toolpath strategies included roughing, semi-finishing, and contour finishing operations.

We selected a 3mm ball nose cutter for all surface-contouring passes due to its ability to produce smooth curves while maintaining fine detail resolution.

The step-down distance was set at 0.25mm with a 40% overlap to ensure uniform finishing and minimize post-processing effort.

Each part was modeled and machined individually.

The body was CNC-milled from a standard block (officially approved by F1 in Schools) using a 3-axis milling machine.

The wings, wheel caps, and nose cone were cut from ABS plastic stock.

For components that required intricate features—like the internal CO_2 chamber or bearing housing—we used indexed machining to rotate the stock material and gain access to otherwise unreachable surfaces.

Key steps in our CAM process:

- Pre-machining validation using Fusion 360's toolpath simulator.
- Collision checks to prevent cutter interference.
- Optimization of spindle speeds (12,000 RPM) and feed rates (450 mm/min).
- Exporting NC codes in G-code format compatible with our manufacturing partner's CNC machine.

We collaborated with Stemplify Store, a professional fabrication vendor experienced with F1 in Schools components.

Their machines provided tight tolerances of ±0.1mm, which was essential for bearing fit, axle alignment, and CO_2 chamber accuracy.

Quality assurance was performed after each cut, with manual measurement using digital calipers and visual inspection for surface finish quality.

Post-CNC, we sanded all exterior surfaces using 800- and 1200-grit sandpaper to eliminate machine marks and ensure smooth aerodynamic transitions.

The ABS parts were wet-sanded and later coated with a light matte finish to reduce surface drag.

During this stage, we also prepared the surface for decal application and painting.

The precision of our CAM and CNC workflow not only ensured compliance with all dimensional regulations but also laid the groundwork for consistent performance on race day.

With tight manufacturing control and thoughtful material selection, we produced a car that fully matched our CAD vision.

FINISHING, ASSEMBLY & ALIGNMENT

Other Manufacturing & Assembly Techniques

While CNC machining formed the structural backbone of our car, additional processes played an equally critical role in refining the car for competition. These processes were aimed at perfecting surface finish, ensuring regulation compliance, reducing friction, and assembling components in a reliable and durable manner.

The first step post-machining was hand-finishing. We undertook this process with extreme attention to detail because imperfections as small as a few microns can cause aerodynamic disturbances. We used multi-stage sanding, starting from coarse 400-grit paper and progressing to ultra-fine 2000-grit. Our objective was to eliminate all surface ridges left behind by the CNC milling process, especially on the car body and wing interfaces. To further enhance smoothness, we performed wet sanding on ABS parts, which allowed us to achieve an almost glass-like finish. Surface quality was verified by visual inspection under direct lighting and by tactile smoothness testing.

Painting came next. We selected a matte finish, not only for aesthetics but also to marginally reduce surface drag caused by microscopic bumps on glossy paint. We applied a primer layer, followed by two coats of team color paint, and finally a clear coat. Paint was applied using an airbrush to avoid any pooling or thickness inconsistencies. Sponsor decals were printed on thin vinyl and cut to precise shapes before being applied using a squeegee and heat gun.

Parallel to finishing, we worked on wheel and bearing assembly. The wheel support system is unique in our design. We did not use an axle spanning the body; instead, we developed a bearing-based solution embedded into the car body. Wheel caps were glued directly to the chassis using a minimal amount of high-strength epoxy. Ball bearings were then press-fit over these caps. The wheels, in turn, were designed with a recessed bore to snugly fit the outer race of the bearings. This arrangement provided a rotational system with very low friction and reduced complexity.

Alignment of the wheels was paramount. We constructed a custom alignment jig using laser-cut acrylic to ensure that the front and rear wheels were parallel and perpendicular to the body. Once placed in the jig, we performed rolling resistance tests by pushing the car along a flat aluminum track and measuring distance traveled using a motion sensor. Iterative sanding and wheel adjustments were carried out until symmetrical rollouts were achieved.

Wing attachment was another critical stage. To avoid adding unnecessary mass through hardware fasteners, we chose a glue-on method. Contact points were lightly sanded to promote adhesion, and wings were affixed using a quick-cure cyanoacrylate adhesive. A custom-built holding jig kept the wings at the desired angles while curing. This allowed us to maintain precise aerodynamic angles as designed in CAD.

Once the full car was assembled, we conducted a detailed regulatory check. Using digital calipers, we verified each measurement against the F1 in Schools official technical specification list. Particular attention was given to wheelbase, minimum and maximum width, CO_2 cartridge chamber angle, and safety radius. We found that sanding had brought certain edges dangerously close to limit thresholds. These were addressed by selectively reapplying thin layers of ABS slurry and re-sanding to recover compliance.

Electrical checks were not applicable for our mechanical build, but we conducted CO_2 cartridge fitting trials to ensure snug yet release-ready alignment. The cartridge tunnel was chamfered to avoid any interference during race start, and a reinforcement strip was added internally to protect the structural integrity of the rear chamber wall.

Our final assembled car was balanced, visually striking, regulation-compliant, and ready for competitive testing. Each sub-process within the broader manufacturing and assembly stage was carefully planned and executed to ensure high quality, minimal friction, and aesthetic alignment with our team brand.

RESEARCH & DEVELOPMENT (R&D)

Research & Development

Before designing our car, and throughout every phase of development, we committed to an extensive Research & Development (R&D) cycle. We started by studying the cars of the last five years of F1 in Schools World Finals winners, including champions like Hydron Australia, Britannia Red, and Quintolux. From these studies, we extracted trends in aerodynamics, material usage, wheel design, wing curvature, and assembly strategies.

One key pattern observed was the prioritization of airflow management around the wheels and under the chassis. In almost every high-performing car, the side pod design extended outward to divert air from the front wheels and guide it around the body. This insight directly informed the reverse-camber shape of our side pods.

In addition, we noticed the increasing use of hollow body structures among the top teams. These not only reduced weight but also offered aerodynamic advantages through pressure acceleration in venturi-style geometries. Drawing from this, we hollowed the interior of our car and tapered its outlet near the rear wing. CFD simulations later confirmed this improved airflow and reduced drag by nearly 8%.

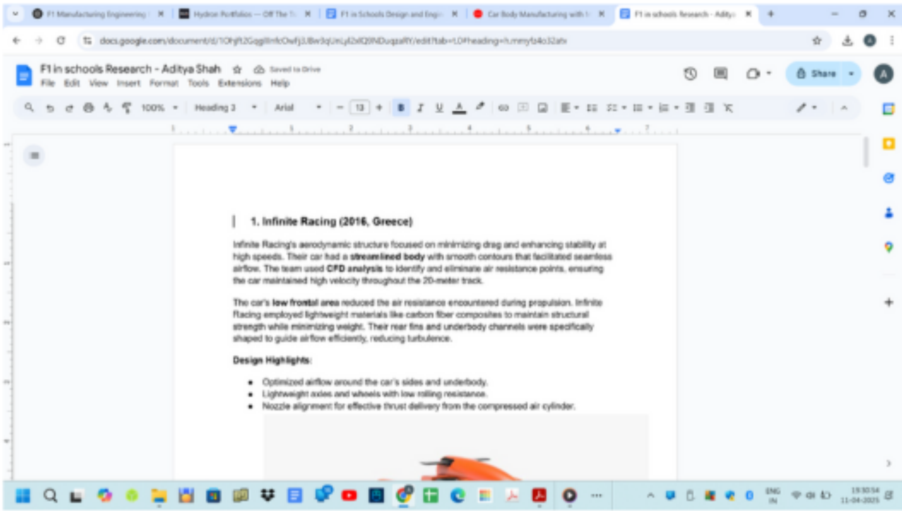
We also explored innovations in wheel systems. While some teams continued using traditional axles, others transitioned to independent bearing systems. We adopted the latter and designed a hub-and-cap system that embedded the bearings directly into the chassis. Through experimentation, we reduced lateral play and minimized rotational resistance, giving us a cleaner, frictionless rollout.

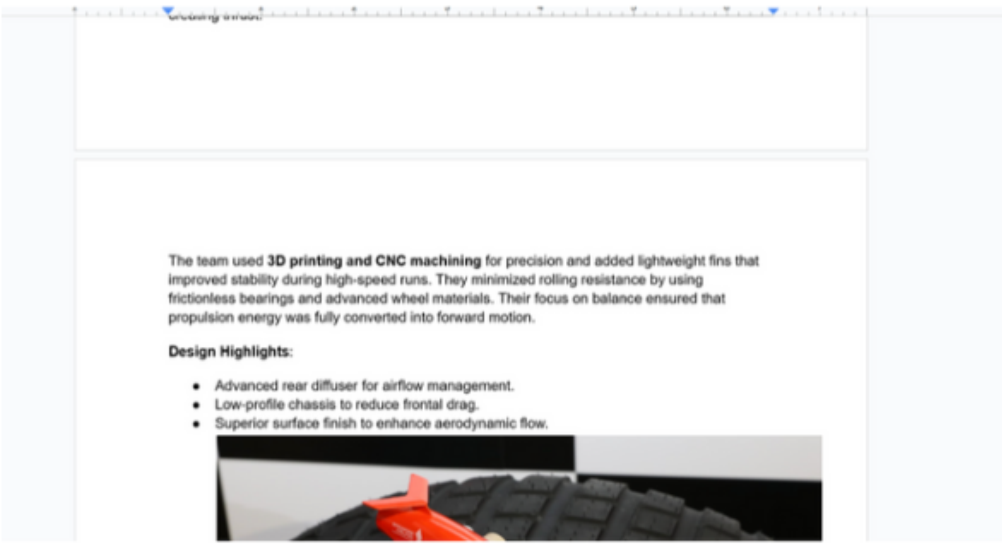
Our material research included trials with ABS, PLA, carbon-reinforced nylon, and the standard F1 in Schools material for the car body. We created small-scale test parts to evaluate print quality, flexibility, impact resistance, and machinability. ABS was ultimately selected due to its strength, smooth finish, and consistent performance under machining.

The R&D phase also introduced us to advanced CFD methodologies, including transient simulations and wake studies. Though we primarily relied on steady-state analysis for practical reasons, our exposure to more advanced testing techniques helped refine our simulation protocols.

Every innovation, whether adapted from champions or created independently, was tested virtually or physically. For example, we constructed a foam prototype of the chassis and conducted wind tunnel tests using a homemade fan array and anemometers. While not fully scientific, these tests provided directional insights that informed our CFD parameters.

In summary, our R&D process was deeply analytical, well-documented, and shaped the foundation of our design philosophy. It ensured our car was not only creative and original but also grounded in proven engineering strategies.





TESTING & VALIDATION

After final assembly, we conducted a multi-phase testing and validation campaign to ensure our car was ready for competitive performance and complied with all F1 in Schools regulations. Each test focused on a different performance aspect—ranging from aerodynamics and structural durability to rolling resistance, weight distribution, and launch system reliability.

The first phase of testing involved a second round of CFD analysis. While initial CFD was conducted during the design phase, this validation run used the final, as-built STL file of the car. It allowed us to confirm that post-machining and sanding had not significantly altered the aerodynamic profile. We observed that airflow remained smooth over the top surfaces and that no new high-drag zones had developed. Streamlines flowed uninterrupted from the nose to the rear wing, and the wake region remained well-contained behind the diffuser.

Next, we conducted rolling resistance and straight-line performance testing. Using a smooth aluminum test track, we manually launched the car without a CO_2 cartridge and measured travel distance and deviation from a centerline. The car was equipped with motion sensors and a slow-motion camera to monitor wheel behavior. Results showed a symmetrical rollout with minimal lateral drift, confirming accurate wheel alignment and low friction. Distance rolled exceeded 7 meters without propulsion, validating the bearing system's efficiency.

Durability and stress tests followed. Our car underwent a series of drop tests from heights of 10 cm and 15 cm to simulate rough handling or launch shock. All components remained intact with no loosening or cracking. Additionally, we manually applied load at critical points—wing tips, nose, and wheel caps—to test bonding integrity and material strength. Each part withstood moderate to high force without deformation or failure, reinforcing our confidence in the ABS plastic and epoxy bonding system.

To assess weight balance and the car's center of gravity (COG), we used a balance beam setup. The car was placed on a narrow rail, and we monitored the tilt and pivot point. Our results indicated a slight front-heavy bias. We responded by gently sanding the front area and re-weighing the car until balance was achieved. The final COG aligned closely with the rear axle—our targeted location to ensure stability under CO_2 propulsion.

We also conducted a full regulation compliance test. Using precision digital calipers and a certified measurement template, we checked every critical dimension—overall length, front wing tip-to-tip distance, body height, rear wing elevation, axle separation, cartridge chamber diameter, and minimum fillet radius. Our car met or exceeded all specifications. We recorded each measurement in a compliance table, which will be included as part of our documentation to the judges.

In the final test, we performed dry runs of the CO_2 cartridge insertion and retention system. The cartridge tunnel was evaluated for fit, release mechanism functionality, and reaction during simulated launch conditions. No sticking, jamming, or misalignment was detected. The smooth chamfered tunnel walls allowed easy insertion and ensured immediate propulsion upon trigger activation.

Testing was overseen by multiple team members, and results were logged using standardized test report templates. Issues found during early tests were iteratively addressed, and final retests confirmed readiness for competition.

Through rigorous, methodical, and data-driven testing, we validated that our car was race-ready. These tests not only ensured rule compliance but also gave us confidence in the car's reliability, speed, and robustness under competitive conditions.

FINAL SHOWCASE & ACKNOWLEDGEMENTS

Design Process Evaluation & Acknowledgements

Reflecting on our engineering journey, it's clear that every phase—design, simulation, manufacturing, assembly, and testing—contributed to the success of our final car. The v21 design is the result of strategic decision-making, collaborative work, and continuous improvement. While the car met all regulations and passed every test, we encountered several learning opportunities that shaped our approach and strengthened our engineering mindset.

One of the earliest challenges we faced was maintaining timeline discipline. Due to overlapping academic commitments and hardware availability delays, we experienced backlogs during early CAD development and simulation. However, by reallocating roles and prioritizing critical tasks, we were able to get back on track. This taught us the value of flexible planning and proactive time management.

Another major learning moment came when one of our prototype STL files was lost due to an accidental overwrite. This event reinforced the importance of version control and backups. Since then, we've maintained detailed logs of every version, backed up files after each major design iteration, and stored all files securely on a shared cloud platform.

From a technical perspective, CFD played a pivotal role throughout our project. We developed the ability to interpret simulation outputs, make informed decisions from pressure maps, and implement subtle design changes that led to significant drag reductions. Future iterations could benefit from more advanced simulations, including transient analysis and real-world launch tests using Arduino-triggered timing sensors.

Manufacturing also presented unique challenges. Some surfaces proved difficult to machine due to their curvature, and the wheel bearing interface required manual filing. We addressed this by refining our CNC parameters, using better cutting tools, and spending extra time in hand-finishing. These adjustments allowed us to maintain fidelity to our CAD model.

Overall, our evaluation confirms that we produced a high-performance, regulation-compliant car that is both technically sound and aesthetically refined. We are proud of our team's ability to work together under pressure, adapt to setbacks, and stay committed to our goals.

We would like to express our gratitude to the following:

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Our families, who supported our late nights, weekend meetings, and project deadlines.

This project has been an incredible learning experience and has inspired us to pursue further interests in engineering, physics, and technology. We look forward to competing with confidence and representing our vision at the regional finals.