# STEM Racing : Engineering your future

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**Abstract**

The STEM Racing challenge, formerly F1 in Schools, is the world's largest secondary school technology program, engaging millions of students globally in a hands-on application of Science, Technology, Engineering, and Mathematics (STEM) principles. Teams design, manufacture, and race miniature CO2-powered Formula 1 cars, aiming to introduce young individuals to engineering in an engaging environment. This guide illuminates the path for aspiring engineers, outlining their critical role, available tools, and essential questions that drive innovation.

In STEM Racing, the engineer is central to success, overseeing design, analysis, manufacturing, and documentation, while ensuring compliance with technical regulations. This role demands balancing creative problem-solving with adherence to constraints and effectively communicating design choices.

This guide will illuminate pathways to essential resources for your engineering journey, helping you understand the types of tools available for design, simulation, and manufacturing, such as computer-aided design (CAD), computer-aided engineering (CAE), and computer-aided manufacturing (CAM) processes.

Rather than providing answers, this guide fosters innovation by prompting fundamental engineering questions. It encourages critical examination of design choices, materials, and manufacturing, guiding you to inquire: "How does the car's profile influence drag?" or "What material properties balance strength and weight?" This approach cultivates a problem-solving mindset, empowering independent research and discovery.

This guide serves as a foundational starting point for your STEM Racing engineering journey, providing initial direction and critical questions, but it is by no means an exhaustive manual for guaranteed success. Engineering demands continuous learning, experimentation, and adaptability. Success hinges on collaborative spirit, iterative design, hands-on application, and learning from both triumphs and setbacks. This guide is not a magic bullet, it serves not to walk you through the entirety of the competition but only to get you started. Success hinges not on reading this guide but on research, innovation, and mastery of the tools and the regulations..

# Contents

# Chapter 1

# The Indispensable Role of the Engineer in the STEM Racing Competition

The STEM RacingTechnology Challenge is the world's largest secondary school technology program, engaging millions of students globally in a hands-on Science, Technology, Engineering, and Mathematics (STEM) experience. This international competition tasks teams with designing and manufacturing miniature Formula 1 cars, following a rigorous engineering process: Research – Design – Analyse – Make – Test – Race. Beyond technical proficiency, it cultivates vital employability skills like leadership, teamwork, and project management. Engineering is one of the core judged components, making the engineer's role pivotal in every stage, from conceptual design and rigorous testing to precise manufacturing, balancing adherence to technical regulations with the pursuit of optimal speed.

## 1.1 Research: Mastering the Science of Speed

The initial and critical phase for a STEM Racing engineer involves comprehensive research into the fundamental scientific and engineering principles that govern high-speed vehicle performance. This theoretical understanding is essential for making informed design decisions. Teams investigate how objects achieve high speeds, building a knowledge base for their car design. The car's speed and stability are influenced by engineering forces such as thrust, drag, lift, weight, and rolling resistance. Understanding how these forces interact and how energy is converted is key. Aerodynamics is paramount, engineers must understand airflow patterns and flow separation. This phase is about building a strong theoretical foundation to guide subsequent design choices.

## 1.2 Design: Innovation Within Regulation

The design phase is an iterative process where engineering teams conceptualize, model, and continuously refine their miniature F1 car. This entire process is rigorously governed by a comprehensive set of technical regulations. Strict adherence to these rules is non-negotiable, as non-compliance can lead to penalties or disqualification. A core challenge for the engineer is to balance the imperative for speed and performance with the absolute necessity of legality. Computer-Aided Design (CAD) software is the primary tool for precise digital modeling, with Autodesk Fusion 360 being widely recommended. Engineers use CAD to create the car body, front wings, rear wings, and wheels, ensuring all components meet specified dimensions and structural requirements. The detailed nature of these regulations compels engineers to engage in "constrained optimization," devising creative solutions within predefined parameters, much like in real-world engineering. CAD also plays a crucial role in verifying compliance and generating files for manufacturing and documentation.

## 1.3 Testing and Optimization: The Power of Simulation

Following the initial design phase, engineers leverage advanced simulation tools for virtual testing and optimization. This significantly reduces the reliance on costly physical prototypes and traditional wind tunnel testing, facilitating rapid design refinement. Computational Fluid Dynamics (CFD) is an indispensable tool for optimizing aerodynamic performance, allowing teams to simulate airflow patterns around the car to fine-tune designs for minimal drag. Ansys is the official global CFD simulation partner, providing free access to software and learning resources. CAD software is also used to analyze the car's center of mass, allowing for virtual adjustments to improve launch efficiency. Stress tests, typically performed using Finite Element Analysis (FEA), are crucial for understanding how individual car parts will react to various forces and loads, ensuring their structural integrity and overall performance. These simulations help engineers validate designs, identify potential weak points, and ensure components can withstand operational forces, contributing to the car's overall strength and stability. The iterative nature of simulation accelerates both learning and design optimization, bridging theoretical understanding with practical application.

## 1.4 Manufacturing: Bridging the Digital and Physical

The manufacturing stage represents the crucial transition from the digital realm to physical reality, where the meticulously designed and rigorously simulated 3D model is transformed into a tangible racing car. This phase demands careful selection of appropriate materials and manufacturing processes to ensure the physical car precisely embodies the optimized digital design and meets regulatory requirements. Computer Numerical Control (CNC) milling is the predominant technique for shaping the STEM Racing car body, often mandated to be machined from the official F1 Model Block material for precision and consistency. 3D printing, an additive manufacturing technique, is invaluable for producing components with intricate geometries or high levels of customization, such as front wings, rear wings, and wheels, offering significant design freedom. Surface finishing, though often overlooked, is critically important for aerodynamic performance and visual appeal, requiring meticulous preparation before painting. The final assembly involves attaching components like wheels, washers, screws, and axles, adhering strictly to guidelines and dimensional tolerances. This stage highlights the synergy between subtractive and additive manufacturing, where processes are chosen based on component requirements, and emphasizes the importance of post-processing for performance.

## 1.5 Documentation: The Engineering Narrative and Justification

Documentation in the STEM Racing competition is a fundamental and vital component, serving as the primary mechanism through which teams articulate their entire engineering process, meticulously justify their design decisions, and demonstrate their understanding to industry professional judges. This comprehensive record summarizes the team's hard work and dedication. The Engineering Portfolio is a cornerstone document, chronicling the team's entire engineering journey, covering research, design ideas, testing, manufacturing, and team identity. Engineering drawings are highly technical, CAD-produced documents critical for precise manufacturing, detailing dimensions and material information for components like the virtual cargo, wheel support structures, nose, and wings. Renderings are high-quality, often photo-realistic, images primarily intended to illustrate the three-dimensional form and aesthetic appeal of the car, crucial for marketing and presentation. This documentation rigorously assesses the professionalism and rigor of the engineering process, demonstrating iterative refinement, problem-solving, and adherence to professional standards, emphasizing that effective communication and robust justification are as crucial as technical prowess.

# Chapter 2

# The tools : what tools will you use during the competition?

## 2.1 3D Modeling

3D modeling is a fundamental tool essential for participation in the competition. It empowers you not only to conceive and design your ideal car but also to perform several crucial functions:

- Verify the car's regulatory compliance by utilizing measurement tools within the 3D modeler.
- Generate technical drawings vital for regulatory submissions and manufacturing purposes. Many 3D modeling tools are equipped with the capability to produce these essential technical drawings, which are mandatory submissions for both national and world finals. Additionally, these drawings are indispensable when collaborating with manufacturers, as they often require precise technical specifications to produce parts accurately.
- Create compelling renderings of the car. Renderings play a significant role in the engineering process, not only as a required submission element but also for establishing and communicating the team's identity and branding.

The 3D modeling software most widely adopted throughout the competition is Autodesk's Fusion 360. This preference is attributed to several distinct advantages:

- Fusion 360 encompasses all the aforementioned functionalities and tools necessary for success in the competition, providing a comprehensive suite for design, compliance checks, drawing generation, and rendering.
- A plethora of resources, are available, be they specifically tailored to the competition or simply generally applicable to 3D modeling, offering opportunities to attain mastery.
- Fusion 360 is renowned for its intuitive interface, making it considerably more accessible and easier for beginners to navigate compared to many of its competitors.
- Furthermore, a robust support network is readily available should you encounter any challenges. The online forums are highly responsive, and direct contacts within Autodesk are accessible for addressing specific questions or technical issues.

To acquire access to Fusion 360, please navigate to the following link: https://www.autodesk.com/education/edu-software/overview. Proceed by clicking on "student" and then follow the steps outlined on the website. For verification purposes, you can furnish any school-related documentation, such as report cards, enrollment documentation, or student identification cards. Once verified, you will be able to download and install the software, enabling you to commence your 3D modeling endeavors.

## 2.2 Simulations

For the competition, simulation tools are crucial for optimizing car performance and validating designs, significantly reducing the need for costly physical prototypes and accelerating the design refinement process. Autodesk Fusion 360, widely used for 3D modeling, provides integrated simulation capabilities directly within its environment, accessible through an educational license. This includes tools for stress analysis (Finite Element Analysis or FEA) to ensure structural integrity, and Computational Fluid Dynamics (CFD) for analyzing airflow patterns to minimize drag. Fusion 360's intuitive interface and comprehensive suite make it highly accessible for beginners, streamlining the transition from design to initial analysis. Beyond Autodesk, Ansys serves as the official global CFD simulation partner for the competition, offering free access to its industry-leading software and learning resources for participants. Within the Ansys suite, Ansys Discovery is highly recommended as the best CFD software for beginners due to its intuitive user experience, real-time feedback, and focus on rapid design exploration and qualitative solutions. It allows teams to quickly test different design iterations and get immediate feedback on aerodynamic performance. However, Ansys Discovery offers less precision and is not suitable for complex problems or when results need to be within a 5-10% accuracy range. If greater precision is required, teams can transition to Ansys Fluent, which is a more advanced and comprehensive CFD solver designed for highly detailed and accurate simulations of complex fluid flows. While Fluent provides accurate quantitative results and is the "gold standard" for precision, it has a steeper learning curve due to its complex interface and advanced features, requiring more skill and experience to operate effectively. Although comprehensive documentation and online resources are available, mastering Fluent requires a more dedicated learning commitment compared to Discovery. Access to Ansys software for students can be obtained via the Ansys website.

You get access to all the Fusion simulation tools at the same time as Fusion 360. To get access to Ansys simulations, go here to download Ansys for students : https://www.ansys.com/academic/students/ansys-student

# Chapter 3

# Learning: how do you master the tools in order to make the best car possible?

**Work in progress, this section is still being written and is not final.**

## 3.1 Fusion 360 : s3d modelling

So you've read through the regulations and you've drawn up some sketches of how you want the car to look. Now you have to design a 3d model of your ideas. When you open Fusion, there are three ways you can design the parts of your car. Each design method has its advantages, its disadvantages and thus, different components of the car will probably be designed with different tools. In this part, I will give a quick overview of each design method as well as other resources to master them and contacts in case you have questions.

### 3.1.1 Solid design

The first way to design is solid design. Solid design works in three steps : sketch, extrude and modify. Solid design is mostly useful for parts that evolve in one direction or are bounded by flat surfaces.

#### Sketch

Sketch is the first step in designing a component through solid design. Sketching is, as the name suggests, creating a drawing that will be the basis of the solid you are designing. The sketch is usually the flatest side or it is normal to the direction in which the solid is the longest. To create a new sketch, press the create a sketch button and choose a plane on which to draw your sketch. You can then draw shapes by either using the shape tools, projecting an already existing body or with lines that you connect to a loop. Just make sure you have a closed shape (visualised with blue shading) or else you won't have anything to extrude. When drawing a line, if you want it to be a specific length/angle, press tab and enter your desired constraints. You can also name constraints to use them later if you need multiple sides to be the same length for example. You can also modify certain parameters of your sketch such as making points automatically snap or not or making it a 3d sketch if you want.

#### Extrude

Once you have finished your sketches, it is time to turn them into solids by giving them another dimension. There are many ways to do this, I'll go through two of them : extrude and loft.

The easiest way to turn your sketch in a body is the extrude tool. To use the extrude tool, select one or multiple faces that you want to turn into bodies and select the extrude tool. Once there, you can extrude in one direction or both. The last part is choosing what to do with the extrusion. You can of course turn it into a new body or component but you can also join it to another body or use it to cut into another body.

Another way to turn a sketch into a solid when you have multiple sketches you want to link together is the loft tool. The loft tool serves to link faces together with a body. To use the loft tool, select it and then select the faces you want to loft together. If you want to use a face that is split with a line, make sure to select the two faces one after another so the tool doesn't try to loft adjacent faces. You can also select intermediate faces that serve as a checkpoint that the loft tool must respect. Finally, you can set rails and centerlines that the tool will follow but these aren't mandatory.

Keep in mind that there is a lot you can do to turn planes into bodies. There is more nuance to the tools, especially the loft tool that you can play around with. Furthermore, there are many other tools that can turn a plane into a body such as the revolve or sweep tools. Each tool has its own use case so make sure to explore them all in order to be able to efficiently tackle any design challenges you might face.

#### Modify

Once you have your base body (created with extrude, loft or another tool) you will want to refine it. To do so, you have a multitude of tools at your disposal such as filet, pull or push as well as face deletion. Each body needing its own refinements as well as each tool being different to use, here is a list of some of the more useful refinement tool we used and what they do :

- Filet : rounds out edges and corners
- Delete face : as the name implies, deletes faces and attempts to repair the body so that you keep a solid and you don't get a surface body. **DOES NOT ALWAYS WORK**.

Add more examples

### 3.1.2 Freeform modeling

Freeform modelling in Fusion 360 lets you sculpt organic shapes using a T-spline–based "Form" environment. It's useful for parts with smooth, flowing surfaces or ergonomic shapes that aren't easily defined by flat planes. Like solid design, freeform follows a few main steps: entering the Form workspace to create a base shape, editing the form to refine the volume, and then finishing by converting to a solid or integrating with other geometry.

#### Create Form

To start sculpting, switch to the Form (also called Sculpt) workspace and click "Create Form." Choose a primitive (box, cylinder, sphere, or pipe) as your starting block. The primitive's faces, edges, and vertices define a T-spline lattice you can manipulate. Pick a plane or existing face to attach the form if needed. Keep in mind that the initial shape should roughly match the overall volume or profile you want to achieve, since drastic changes later can become harder to manage.

#### Edit Form

With the form created, use tools like Edit Form (push/pull), Insert Edge, Insert Point, and Crease to shape it. Select faces or edges and drag to adjust curvature; press and hold modifiers (e.g., Alt/Option) to move individual vertices or entire edge loops. Use symmetry options early to ensure the model stays balanced. You can also add supporting geometry by inserting edge loops where you need sharper transitions or more control. The "Tweak" handles appear when you select sub-entities—drag them to refine thickness or curvature. Keep checking smoothness and flow by observing how surface highlights move across the form.

#### Finish Form

Once the sculpt is close to the desired shape, click "Finish Form" to convert the T-spline into a solid or surface body. You can then use solid-modelling tools—Combine, Fillet, Shell, or Boolean operations—to integrate the sculpt with other parts. If needed, split faces or use Patch tools to repair surfaces before conversion. Finally, apply appearances or prepare the model for manufacturing or rendering. Remember that freeform works best when you plan the general silhouette first, then iteratively refine details, leveraging symmetry and edge control to balance smoothness with any necessary sharp features.

### 3.1.3 Generative Design

Generative design in Fusion 360 uses cloud-powered algorithms to explore hundreds (even thousands) of design alternatives based on your functional requirements. Instead of manually sketching and extruding or sculpting form, you define goals and constraints, let Fusion iterate automatically, then choose and refine the best solution. It's ideal for lightweight structures, organic lattices, and designs that balance competing performance criteria.

Having not used generative design throughout the competition, I am not in a position to teach you about the tool. Furthermore, because of there being a prize depending on your mastery of the tool, it could be considered unfair to give you a headstart. Thus, I encourage you to explore the tools yourselves and come to me with any questions. Have fun!!

## 3.2 Simulations : Ansys Discovery, Ansys Fluent and Fusion

Once you have finished designing the car, you'll want to optimize it using simulations. The most common simulations used throughout the competition are aerodynamic simulations. These serve to optimize the aerodynamics of your car, to help you minimize drag. However, there are many other types of simulations that are key to success.