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# A Comprehensive Framework of Best Practices for Designing, Implementing, and Competing with a Formula SAE Race Car

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**Abstract**

Designing and constructing a Formula SAE (FSAE) vehicle is a premier engineering capstone project. This paper presents a comprehensive framework centered on five critical pillars: strict rule adherence, systems engineering, rigorous project management, design for manufacturability, and iterative testing. By analyzing these pillars through decision matrices and process flowcharts, the framework provides actionable guidance for academic teams. A central theme is that a reliable, well-tested vehicle consistently outperforms a theoretically superior but fragile design. The study addresses both Internal Combustion Engine (ICE) and Electric Vehicle (EV) platforms, reflecting the modern landscape of the Formula Student series. Key lessons emphasize recognizing regulatory limitations, maintaining cohesive system integration, and strictly allocating time for validation. The provided resources—including comparative data tables and failure mode frameworks—serve as a modular toolkit for teams to optimize their unique programs. Ultimately, success depends on the transition from theoretical engineering to a physical prototype that can endure the rigors of competition. Regardless of powertrain choice, the core principles of feasibility and thorough testing remain the ultimate drivers of performance.

**Keywords:** Formula SAE; Design for manufacturability; Vehicle dynamics; Electric vehicle.

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## 1. Introduction

The Formula SAE (FSAE) competition, organized by SAE International, challenges university teams to conceive, design, fabricate, develop, and compete with small, open-wheel, formula-style racing cars. Since its inception in 1981, FSAE has grown into the world's premier collegiate engineering design competition, with over 600 teams participating across events in North America, Europe, Australasia, and Asia. The competition's enduring success lies in its unique ability to bridge the gap between classroom theory and the high-pressure realities of industry-level product development.

The challenge is multifaceted: teams must not only engineer a high-performance vehicle but also develop a comprehensive business case, manage a budget, present their design philosophy to industry judges, and demonstrate the car's performance through a series of dynamic events including acceleration, skid-pad, autocross, and a grueling 22-kilometer endurance race. This holistic evaluation mirrors the real-world demands placed on automotive engineering professionals, making FSAE an unparalleled educational platform. This paper provides a structured and detailed framework for guiding a senior design team through the process of building a competitive Formula-style race car. It identifies five critical pillars that, based on extensive observation of successful and unsuccessful programs, consistently separate cars that compete effectively from those that never reach the starting line. Each pillar is explored in depth, supported by tables, flowcharts, and figures that teams can adapt as practical tools for their own programs. The selection of these specific five pillars was derived from a systematic historical analysis of Formula SAE competition outcomes spanning several decades. To construct this framework, a retrospective review protocol was applied to extensively observe both successful and unsuccessful collegiate programs, isolating the core variables that consistently dictate whether a vehicle competes effectively or fails to reach the starting line. By synthesizing this historical performance data with expert insights from long-standing faculty advisors and industry judges, the myriad challenges of race car development were distilled into five distinct, foundational categories. These five pillars, strict rulebook adherence, systems engineering, project management, design for manufacturability, and rigorous validation, were identified as the minimum necessary dimensions required to holistically address the competition's multi-disciplinary demands without overcomplicating the pedagogical model for student engineering teams.

The design and development of a Formula SAE or Formula Student race car is a complex, multidisciplinary engineering challenge. Foundational principles of vehicle dynamics are heavily relied upon, with seminal texts by Milliken and Milliken [15], Gillespie [9], and Dixon [7] providing the theoretical bedrock for suspension geometry, handling, and race car behavior. Although published decades ago, Carroll Smith's Tune to Win [22] remains highly relevant to modern Formula SAE

practice because it provides the essential theoretical bedrock for understanding suspension geometry, handling, and overall race car behavior. While contemporary FSAE teams rely extensively on advanced, computer-aided simulation and optimization tools, the successful application of these modern techniques requires a seamless integration with classical mechanical engineering principles. By establishing the foundational concepts of vehicle dynamics, Smith's work ensures that student engineers comprehend the fundamental physical interactions of the chassis and suspension before attempting to optimize them through modern software. These specific automotive principles are supported by broader mechanical engineering and design methodologies, including classical mechanics [12], material selection [1], and design for manufacturability and assembly [3, 24]. Furthermore, all theoretical and physical designs must strictly adhere to continuously updated regulatory frameworks. Vehicles must comply with comprehensive safety and structural guidelines set forth by SAE International for both internal combustion [19] and electric vehicles [20], as well as regional variations like the Formula Student Germany rules [8]. The structural integrity and dynamic response of the chassis and suspension systems are critical areas of continuous research. Early studies established the vital relationship between chassis torsional stiffness and handling balance [6]. Recent literature heavily emphasizes computer-aided optimization to maximize strength while reducing weight. This includes the extensive use of Finite Element Analysis (FEA) for chassis optimization [2] and physical dynamic testing to validate simulated models of car bodies [4].

Suspension and steering systems are similarly scrutinized. Researchers have explored various mathematical modeling techniques to optimize passive suspension systems [16] and have detailed the rigorous development processes required for FSAE steering prototypes [18]. At the component level, the wheel uprights face significant dynamic loads; recent studies have successfully applied parametric design, topology optimization, and fatigue life analysis to create highly efficient, lightweight uprights for electric FSAE cars [13, 26]. Reliable deceleration is just as critical as acceleration. Literature surrounding FSAE braking systems focuses on the integration of theoretical design with practical simulation and physical testing to ensure safety and performance under racing conditions [5, 11]. In terms of propulsion, the literature reflects the motorsport industry's dual focus on optimizing traditional combustion engines and advancing electric vehicle (EV) technology. For combustion vehicles, numerical investigations have been used to fine-tune load control systems in turbocharged engines to balance fuel efficiency with power output [17]. Meanwhile, the shift toward electric racing has driven research into advanced all-wheel-drive electric propulsion systems intended to maximize tractive performance [10], as well as optimized transmission and wheel systems derived from higher-tier electric racing like Formula E [25].

Aerodynamic performance has become a major differentiator in modern motorsports. Research highlights the importance of understanding complex flow structures—such as floor aerodynamics in Formula 1—to generate efficient downforce [21]. In the context of FSAE, engineers rely heavily on CFD simulations to predict transmitted tire reaction forces and overall vehicle stability [14]. Pushing the boundaries of traditional simulation, cutting-edge research has recently introduced AI-assisted CFD to rapidly optimize the angle of attack for multi-element wings, significantly enhancing aerodynamic efficiency [23]. The provided literature illustrates that modern Formula SAE design requires a seamless integration of classical mechanical engineering theory [12, 15] with advanced, computer-aided optimization techniques [2, 23]. Whether optimizing an electric powertrain, reducing the mass of an upright, or maximizing aerodynamic downforce, successful vehicle development relies on iterative simulation validated against strict regulatory standards [8, 19, 20].

Despite the wealth of highly specialized research focusing on the theoretical optimization of individual vehicle subsystems, a significant gap remains in the current literature regarding the holistic execution of the project. Specifically, existing literature lacks a comprehensive, systems-level framework that integrates technical component design with rigorous project management, strict regulatory compliance, and practical manufacturability assessments for student engineering teams. This paper addresses this critical void by proposing a unified, five-pillar framework designed to guide teams through the entire vehicle development lifecycle. By shifting the academic focus from isolated theoretical optimization to systemic reliability and cross-disciplinary integration, this framework provides actionable strategies to help teams successfully navigate the complex transition from an initial concept to a competition-ready vehicle.

## 2. Competition Overview and Scoring

Understanding the scoring breakdown is foundational to effective design prioritization. The FSAE competition allocates points across both static and dynamic events. A common strategic error made by novice teams is to focus exclusively on dynamic performance (speed) while underestimating the weight of static events, which collectively account for 325 of the total 1000 points. Table 1. presents the standard FSAE scoring distribution.

Table 1.: Standard FSAE Competition Scoring Distribution (1000 Total Points)

| Event Category | Max Points | % of Total |
|---|---|---|
| Engineering Design | 150 | 15.0% |
| Cost & Manufacturing Analysis | 100 | 10.0% |

| | | |
|---|---|---|
| Business Presentation | 75 | 7.5% |
| Acceleration | 100 | 10.0% |
| Skid-Pad | 75 | 7.5% |
| Autocross | 125 | 12.5% |
| Endurance | 275 | 27.5% |
| Fuel Efficiency / Energy | 100 | 10.0% |
| **TOTAL** | **1000** | **100%** |

As Table 1. illustrates, the endurance event alone is worth 27.5% of the total score, making vehicle reliability arguably the single most important design objective. A car that completes endurance will almost always outscore a faster car that suffers a mechanical failure and does not finish (DNF). This insight should fundamentally shape every design decision made during the project lifecycle.

## 3. Strict Adherence to The Rulebook

The FSAE rulebook, published annually by SAE International, functions as the definitive client specification for the project. It establishes mandatory constraints on virtually every aspect of the vehicle, from the minimum inner diameter of the intake restrictor (20 mm for gasoline-powered vehicles) to the exact height of the main roll hoop above the driver's helmet. The most common and costly point of failure for college teams is an insufficient understanding of these regulations. A vehicle that fails technical inspection, regardless of its engineering sophistication, is reduced to a static display piece that cannot participate in any dynamic event.

### *3.1 Understanding the Rulebook as a Design Specification*

The rulebook should be treated with the same gravity as a contractual specification in industry. Each section imposes constraints that define the design space within which the team must operate. Key regulatory areas include the structural requirements for the chassis and roll hoops, driver protection via impact attenuators, fuel system safety, electrical system specifications, and ergonomic requirements such as the 95th-percentile male driver template and the five-second egress rule.

Teams are strongly advised to assign individual members as "rulebook owners" for specific sections, making each member the subject-matter expert on the regulations governing their subsystem. A cross-referenced compliance matrix should be maintained throughout the design phase and updated

continuously. Fig. 1 illustrates the iterative compliance verification workflow recommended for FSAE design teams.

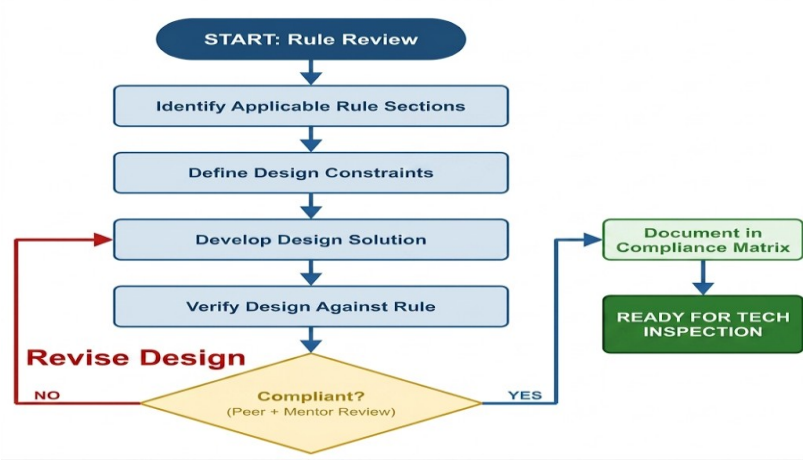



Fig.1: Rulebook Compliance Verification Workflow, From Rule Identification to Technical Inspection Readiness

### *3.2 Technical Inspection: The Gate to Competition*

Technical inspection at competition is a multi-stage process comprising mechanical inspection, tilt testing (to verify the vehicle does not leak fluids at a 45-degree and 60-degree tilt), a noise test, a rain test for electrical vehicles, and a brake test. Table 2. summarizes the key inspection areas and common failure modes observed in competition.

Table 2.: Technical Inspection Areas, Requirements, and Common Failure Modes

| **Inspection Area** | **Key Requirements** | **Common Failures** |
|---|---|---|
| Chassis / Frame | Min. tube specs, triangulation, SES | Unapproved tube material or wall thickness |
| Roll Hoops | Height above helmet, bracing angle | Insufficient bracing, incorrect supports |
| Impact Attenuator | Approved data or IA test report | Missing or unapproved attenuator |
| Driver Egress | 5-second exit with full harness | Tight cockpit, harness interference |
| Fuel System | Tank mounting, vent routing, firewall | Improper fuel line routing or leaks |
| Electrical (EV) | HV insulation, BSPD, IMD, shutdown circuit | Shutdown circuit logic errors |
| Tilt Test | No leaks at 45° and 60° | Oil or coolant leaks under tilt |

| | | |
|---|---|---|
| Brake Test | All four wheels lock simultaneously | Insufficient braking or uneven lock-up |

## 4. Systems Engineering and Cross-Disciplinary Integration

A Formula SAE car is a complex, coupled system of systems. The vehicle's performance is an emergent property arising from the interaction of its chassis, suspension, powertrain, aerodynamics, electronics, and driver interface. Treating these as independent modules that can be designed in isolation and bolted together at the end is the second most common cause of project failure. Effective systems engineering requires a rigorous approach to architecture definition, interface management, and continuous integration.

### *4.1 Vehicle Architecture and Packaging*

The first critical system-level decision is the selection of the overall vehicle architecture. This includes the choice of powertrain (ICE vs. EV), frame type (steel spaceframe, aluminum monocoque, or carbon fiber monocoque), and drivetrain configuration (single motor/engine with chain drive, differential, or individual wheel motors). These decisions cascade through every subsystem and must be resolved early in the conceptual design phase. Fig. 2. presents a system interaction map illustrating the coupling between major vehicle subsystems.

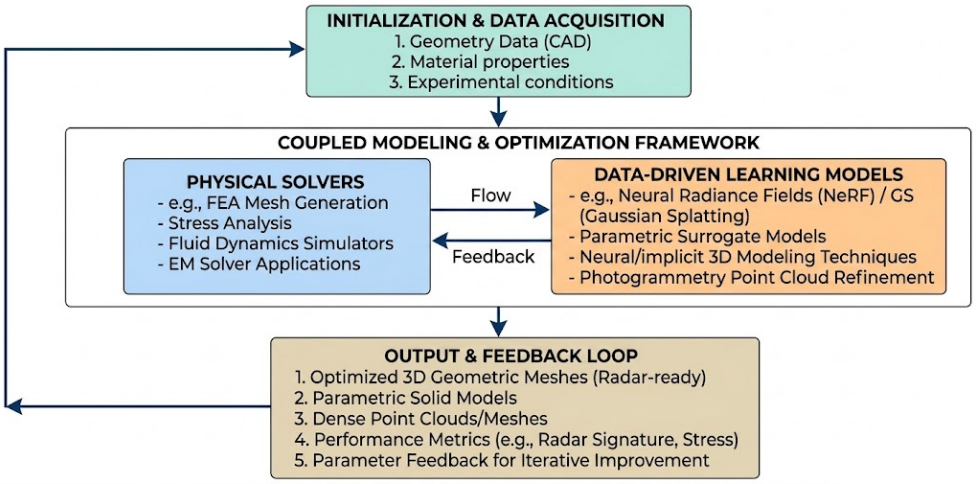



Fig. 2.: System Interaction Map, Map, Majorystem Coupling in a Formula SAE Vehicle

The packaging process begins with defining the driver envelope using the required 95th-percentile template and the Percy template for visibility. Around this, the primary structure (frame or monocoque) is designed, establishing the mounting points and spatial constraints for all other subsystems. The powertrain and drivetrain dictate the rear geometry, while the suspension kinematics define the front

and rear track widths and the attachment point requirements on the chassis. Fig. 3. illustrates a typical FSAE vehicle packaging layout, highlighting the spatial allocation for each major subsystem.

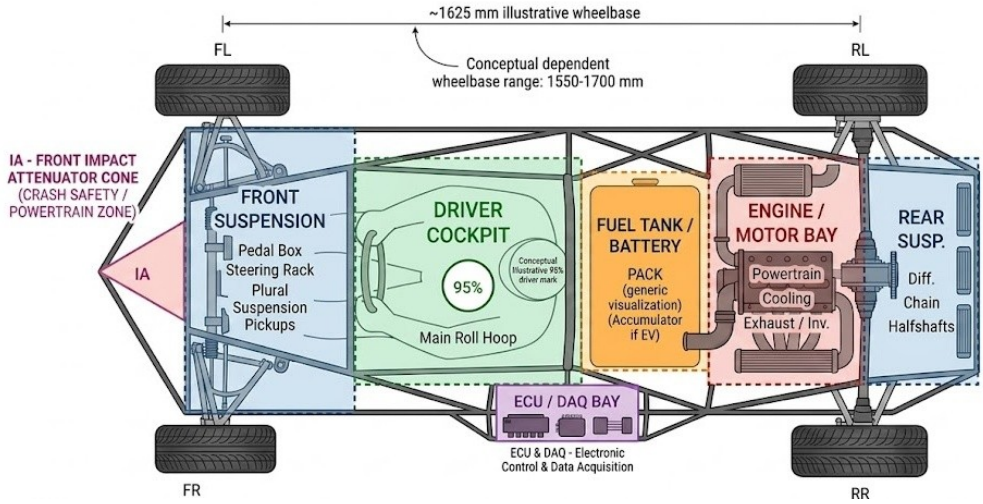



Fig. 3: Typical Formula SAE Vehicle Layout, Top View Showing Major Subsystem Packaging Zones

*4.2 The Nervous System: Electrical and Electronic Integration*

While mechanical systems naturally dominate initial attention, electrical and electronic architecture is frequently the subsystem that determines competition-day reliability. The wiring harness is the vehicle's nervous system, connecting the engine control unit (ECU), sensors, actuators, dashboard, data acquisition system, and safety circuits. A poorly routed harness is susceptible to heat damage from the exhaust, vibration-induced connector failures, and electromagnetic interference (EMI).

Best practices for electrical system design include defining a complete wiring diagram before any physical routing begins, using automotive-grade connectors (such as Deutsch DTM or Amphenol AT series), implementing proper strain relief at every connector, protecting all harness branches with abrasion-resistant conduit, and integrating a comprehensive data acquisition system from day one. The data acquisition system should capture at minimum RPM, throttle position, coolant temperature, oil pressure, wheel speeds, lateral and longitudinal acceleration, and steering angle. Fig. 4 presents a representative electrical system architecture block diagram.

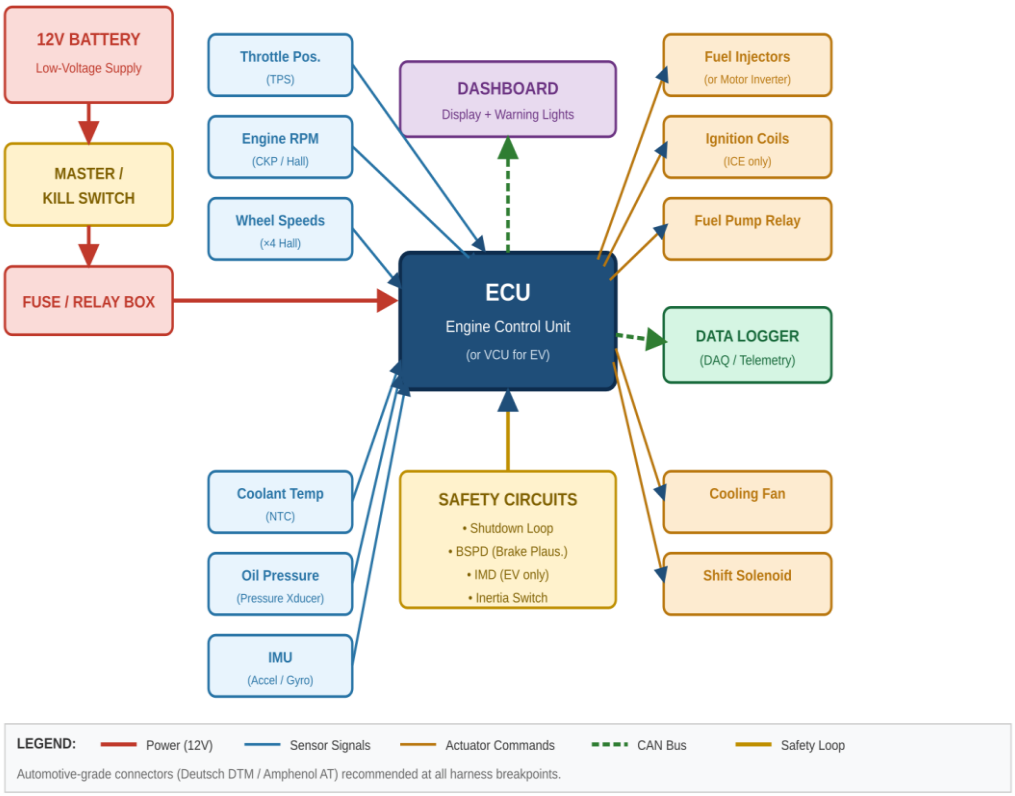



Fig. 4.: Electrical System Architecture Block Diagram, Signal and Power Distribution Overview

### *4.3 Powertrain Selection: ICE versus Electric*

The choice between an internal combustion engine (ICE) and an electric powertrain (EV) is one of the most consequential architectural decisions. Table 3. presents a comparative analysis across key technical and programmatic dimensions.

Table 3.: Comparative Analysis of ICE and Electric Vehicle Powertrain Platforms

| **Parameter** | **ICE Platform** | **EV Platform** |
|---|---|---|
| Typical Power Output | 60–80 kW (with 20mm restrictor) | Up to 80 kW peak (rules limited) |
| Torque Delivery | Narrow powerband, requires tuning | Instant, flat torque curve |
| Typical Vehicle Weight | 180–230 kg | 200–280 kg (battery mass) |
| Complexity Level | Moderate (engine tuning, exhaust) | High (HV safety, BMS, inverter) |
| Budget (Typical) | $15,000–$30,000 | $25,000–$50,000+ |
| Safety Requirements | Standard (fuel, rollover) | Extensive HV safety systems |
| Knowledge Transfer Risk | Lower (widespread expertise) | Higher (specialized HV skills) |
| Industry Relevance | Declining but still relevant | Growing, high employer demand |
| Noise at Competition | Must pass noise test (103–110 dBC) | No noise constraint |

For first-year teams, the ICE platform generally presents a lower barrier to entry due to the availability of well-documented single-cylinder motorcycle engines (such as the Honda CBR600RR, Yamaha YZF-R6, or KTM 690 for singles), extensive community knowledge, and simpler safety requirements. However, teams at institutions with strong electrical engineering programs may find the EV platform aligns better with their core competencies and provides more relevant industry experience.

## 5. Project Management and Mentorship

Building a Formula SAE car within a single academic year is an exercise in ruthless time management. The project timeline spans approximately 8–10 months from initial concept to competition day, with the manufacturing, assembly, and testing phases consuming the majority of calendar time. The most frequently cited axiom in the FSAE community encapsulates the priority: a car finished one month early will beat a 'better' car finished one day before competition. This is because the 'finished' car has no time for the critical testing, tuning, and driver training that ultimately determines on-track performance.

### *5.1 The Master Timeline*

A well-structured project timeline divides the academic year into distinct phases with hard deadlines. Fig. 5. presents the recommended project flowchart from concept through competition.

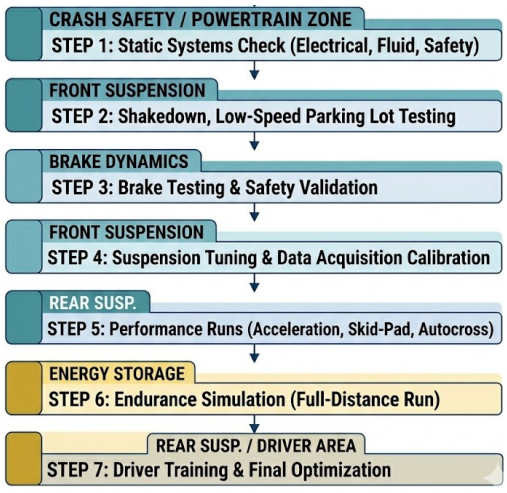



Fig. 5.: Recommended Project Timeline Flowchart, Seven Phases from Concept to Competition

Critical to this timeline is the concept of "design freeze." Once a subsystem enters the manufacturing phase, design changes must be formally reviewed and approved, as changes during manufacturing are exponentially more costly in time and budget than changes made during the design phase. Teams should target a design freeze by the end of month 4, leaving months 5 through 7 for manufacturing and procurement.

### *5.2 Team Structure and Knowledge Transfer*

Effective team structure is as important as effective engineering. The recommended organizational model consists of a project manager or team captain, subsystem leads for each major area (chassis, suspension, powertrain, electronics, aerodynamics, business/cost), and junior members assigned to each subsystem group. Table 4. outlines a recommended team structure.

Table 4.: Recommended Team Organizational Structure and Role Allocation

| Role | Responsibility | Typical Team Size | Skill Focus |
|---|---|---|---|
| Team Captain / PM | Overall coordination, timeline | 1 | Leadership, planning |
| Chief Engineer | Technical integration | 1 | Systems engineering |
| Chassis Lead | Frame design, IA, bodywork | 3–4 | Structures, welding |
| Suspension Lead | Kinematics, uprights, hubs | 3–4 | Dynamics, machining |
| Powertrain Lead | Engine/motor, drivetrain, cooling | 3–4 | Thermodynamics, tuning |
| Electronics Lead | Wiring, ECU, DAQ, safety circuits | 2–3 | EE, firmware, sensors |
| Aero Lead | Wings, diffuser, bodywork | 2–3 | CFD, composites |
| Business / Cost Lead | Cost report, business plan | 2–3 | Finance, presentation |

Knowledge transfer is a perennial challenge for FSAE teams due to the natural turnover inherent in student organizations. Experienced seniors graduate each year, potentially taking critical institutional knowledge with them. To mitigate this, teams should implement structured mentorship pairing (each senior mentors a specific junior), maintain comprehensive design documentation in a centralized digital repository, and conduct formal design reviews where outgoing members present their rationale and lessons learned.

## 6. Design For Manufacturability and Reliability

Students, driven by ambition and inspired by Formula 1 technology, naturally gravitate toward the most advanced and lightweight solutions available: carbon fiber monocoques, 5-axis CNC-machined titanium uprights, topology-optimized 3D-printed components, and complex aerodynamic packages with multi-element wings. While such technologies are laudable goals for mature programs, they are frequently inappropriate for teams with limited manufacturing resources, budget constraints, or insufficient composites experience. The Design for Manufacturability and Assembly (DFMA)

philosophy demands that every component be designed not in isolation but in the context of the team's actual fabrication capabilities.

### *6.1 Capability Assessment Matrix*

Before committing to a design approach, teams should conduct an honest assessment of their available manufacturing capabilities. Table 5. provides a capability assessment framework that maps design choices to required resources.

Table 5.: Design for Manufacturability Assessment, Simple vs. Advanced Design Options

| Component | Simple Design | Advanced Design | Skill Req. | Risk Level |
|---|---|---|---|---|
| Frame | Steel spaceframe (TIG) | CF monocoque | High | Very High |
| Uprights | 6061 Al, 3-axis CNC | Ti, topology-optimized | Very High | Very High |
| A-Arms | Steel tube, welded | CF tube, bonded inserts | High | High |
| Bodywork | Fiberglass layup | Pre-preg CF, autoclave | High | Moderate |
| Exhaust | Mild steel, mandrel bent | Inconel, equal length | Very High | Moderate |
| Wiring | Mil-spec, Deutsch connectors | Custom PCB, CAN bus | High | High |
| Brakes | OEM calipers, custom rotors | Custom calipers, CF rotors | Very High | Very High |

### *6.2 The Reliability Imperative*

Reliability is the ultimate performance metric in FSAE. The mathematical argument is straightforward: completing the endurance event, even at moderate pace, is worth up to 275 points. A DNF yields zero points from endurance and zero from the efficiency event (an additional 100 points). Therefore, a slow but reliable car that finishes endurance can earn up to 375 points from those two events alone, while a theoretically faster car that breaks down earns zero. This 375-point swing dwarfs any advantage that might be gained from shaving seconds off lap times with exotic components.

Design for reliability means selecting proven components where possible, using appropriate safety factors (a minimum of 2.0 for static loads, 3.0 or higher for fatigue-critical components), performing thorough failure mode and effects analysis (FMEA) on every critical subsystem, and designing with inspection and serviceability in mind. Components should be accessible for quick repair, and the team should carry a complete set of spare parts for all known wear items. Fig. 6. presents the standard FMEA process flow applied to FSAE subsystems.

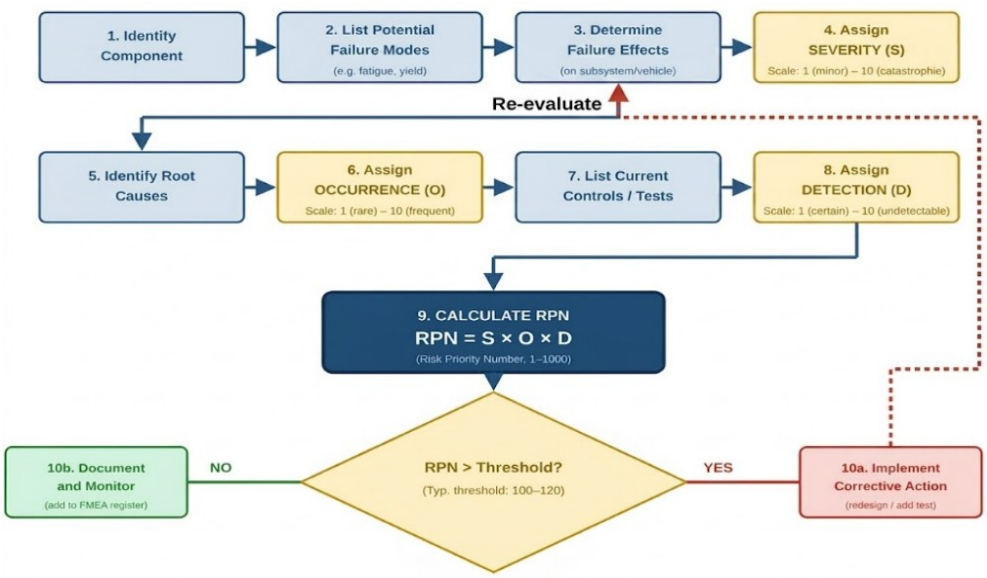



Fig. 6.: Failure Mode and Effects Analysis (FMEA) Process Flow for Critical Vehicle Components

## 7. Testing, Validation, and Iteration

The assembly of the car marks not the end of the engineering process but its midpoint. The testing phase is where theoretical designs meet physical reality, and it is during this phase that the difference between a competitive car and a display piece becomes most apparent. Teams that allocate insufficient time for testing consistently underperform, regardless of the sophistication of their design.

### *7.1 Simulation and Analytical Validation*

Modern FSAE teams employ a suite of simulation tools throughout the design process. Finite Element Analysis (FEA) is used to validate the structural integrity of the chassis, suspension components, and mounting brackets under both static and dynamic loading conditions. Computational Fluid Dynamics (CFD) is employed by teams running aerodynamic packages to predict downforce, drag, and flow behavior around the vehicle body. Lap simulation software, such as Optimum Lap or custom MATLAB models, enables the team to predict overall vehicle performance and evaluate the sensitivity of key design parameters.

However, simulation is a tool for design guidance, not a substitute for physical testing. FEA results are only as accurate as the boundary conditions and material models used, and CFD predictions are particularly sensitive to mesh quality and turbulence modeling assumptions. All critical simulation results should be correlated against physical test data wherever possible. Fig. 7. illustrates the recommended simulation-to-validation correlation workflow.

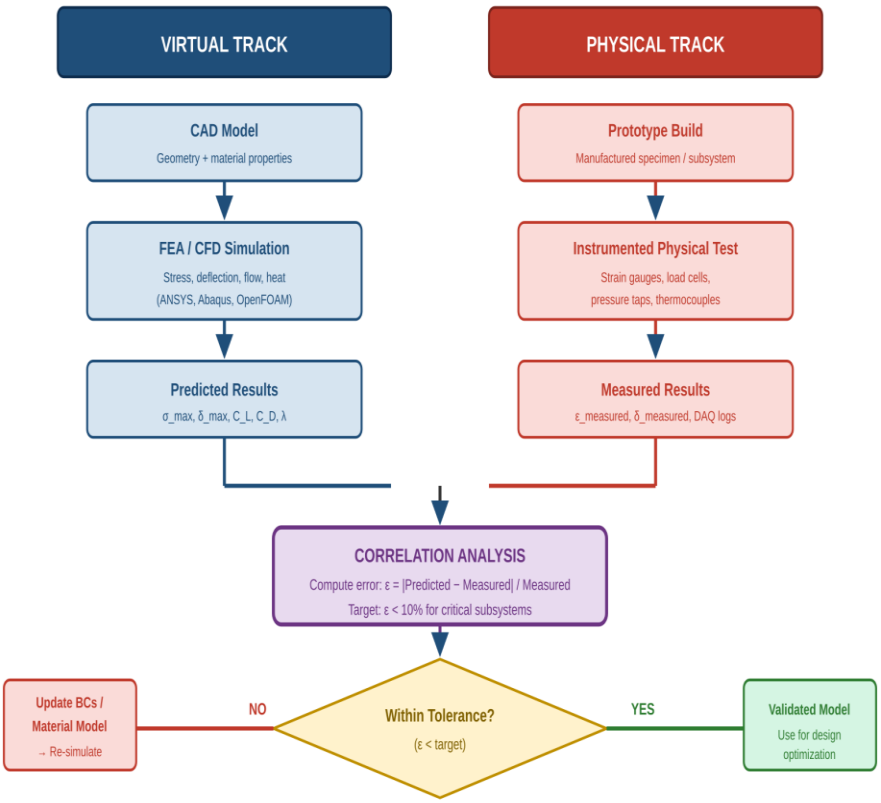



Fig. 7.: Simulation-to-Validation Correlation Workflow, Bridging Virtual and Physical Testing [26, 27]

### *7.2 Physical Testing Protocol*

The physical testing phase should follow a structured protocol that progresses from static checks to low-speed functionality testing and finally to high-speed performance testing. Fig. 8. presents the recommended testing flowchart.

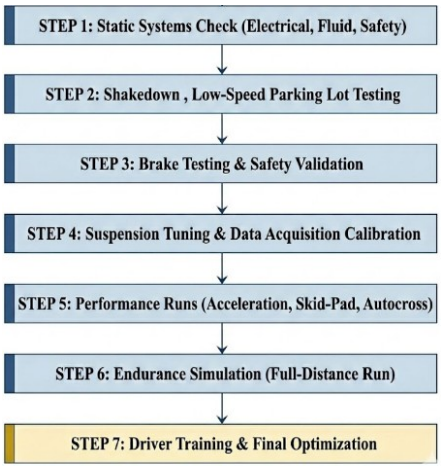



Fig. 8.: Recommended Physical Testing Protocol Flowchart

Each step in the testing protocol serves a specific purpose. The static systems check verifies that all electrical connections are correct, all fluid systems are leak-free, and all safety systems (kill switches,

brake over-travel switches, fire extinguisher) are functional before the car moves under its own power. The low-speed shakedown identifies basic mechanical issues such as clearance problems, binding in the steering or suspension, and overheating. Only after these fundamental checks are passed should the team progress to performance testing.

The endurance simulation is particularly critical. The team should aim to run the full 22-kilometer endurance distance at least three times before competition. Each run should be followed by a thorough inspection of all components, with particular attention to fastener torques, fluid levels, tire wear, and any signs of fatigue or cracking. Issues discovered during endurance simulation testing can be resolved methodically in the shop; the same issues discovered at competition result in a DNF.

### *7.3 Data-Driven Iteration*

The data acquisition system installed on the vehicle should be actively used during testing to drive engineering decisions. Table 6. outlines the minimum recommended sensor suite and the engineering insights each channel provides.

Table 6.: Minimum Recommended Data Acquisition Sensor Suite

| **Sensor Channel** | **Sensor Type** | **Engineering Insight** | **Tuning Impact** |
|---|---|---|---|
| Engine RPM | Hall-effect / inductive | Powerband utilization | Gear ratio selection |
| Throttle Position | Potentiometer / Hall | Driver input correlation | ECU mapping |
| Wheel Speed (x4) | Hall-effect | Slip ratio, ABS behavior | Differential tuning |
| Lateral Acceleration | MEMS accelerometer | Cornering performance | Spring/ARB rates |
| Long. Acceleration | MEMS accelerometer | Braking / accel. performance | Brake bias |
| Steering Angle | Rotary potentiometer | Understeer / oversteer | Alignment settings |
| Damper Potentiometer | Linear potentiometer | Ride height, roll, pitch | Damper settings |
| Coolant Temperature | NTC thermistor | Cooling system adequacy | Radiator sizing |

| | | | |
|---|---|---|---|
| Oil Pressure | Pressure transducer | Lubrication health | Oil system design |

## 8. Integrated Design Decision Framework

To assist teams in making disciplined, evidence-based design decisions, this section presents a weighted decision matrix methodology. Every significant design choice, from frame material selection to aerodynamic package complexity, should be evaluated against a consistent set of criteria that reflect the team's strategic priorities. Table 7. demonstrates this methodology applied to a frame material selection decision.

Table 7.: Weighted Decision Matrix, Frame Material Selection (Scale 1–10, 10 = Best)

| Criterion | Weight | Steel Tube | Al Mono. | CF Mono. | Hybrid |
|---|---|---|---|---|---|
| Weight | 0.15 | 5 | 7 | 9 | 8 |
| Stiffness | 0.15 | 6 | 8 | 9 | 7 |
| Mfg. Ease | 0.25 | 9 | 5 | 3 | 6 |
| Cost | 0.20 | 9 | 5 | 3 | 6 |
| Repairability | 0.15 | 9 | 4 | 2 | 5 |
| Timeline Risk | 0.10 | 9 | 5 | 3 | 5 |
| **Weighted Total** | **1.00** | **7.85** | **5.55** | **4.35** | **6.15** |

In this example, the steel spaceframe achieves the highest weighted score (7.85) for a team that prioritizes manufacturability, cost, and repairability, typical priorities for a first- or second-year team. More experienced teams with established composites capabilities and larger budgets might justifiably weigh the performance criteria (weight, stiffness) more heavily, shifting the optimal choice toward an aluminum or carbon fiber monocoque. The methodology itself is more important than the specific scores, which should be calibrated to each team's unique circumstances.

## 9. Cost and Budget Management

Financial management is an integral part of the FSAE experience and is directly assessed through the Cost and Manufacturing Analysis event (worth 100 points). Teams must submit a detailed cost report documenting the manufacturing cost of every component on the vehicle using SAE's standardized cost

tables. Beyond the competition requirement, effective budget management ensures that the project does not stall due to funding shortfalls during critical procurement phases.

A typical competitive FSAE team operates on a total annual budget of $20,000 to $60,000, depending on the powertrain type, manufacturing ambition, and travel costs. Funding typically comes from a combination of university allocations, corporate sponsorships (both cash and in-kind), fundraising activities, and student organization fees. Teams should aim to secure at least 70% of their projected budget before the manufacturing phase begins to avoid costly delays. Fig. 9. presents a typical FSAE team budget allocation by subsystem category.

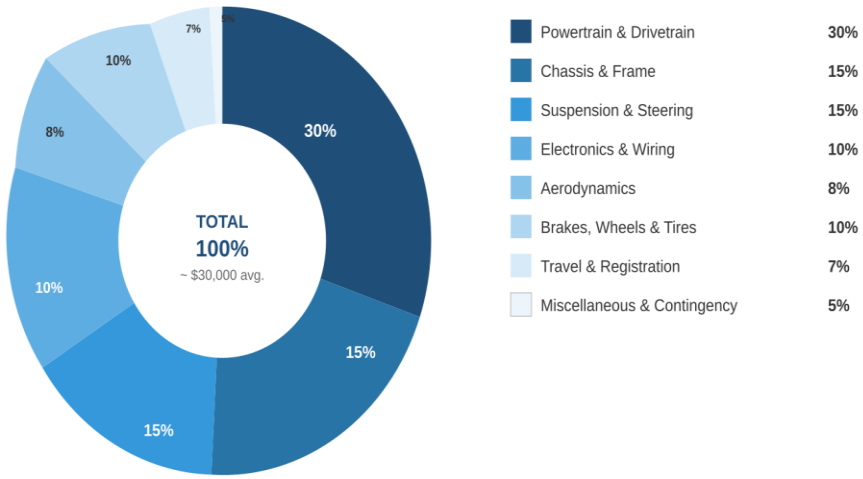



Fig. 9.: Typical FSAE Team Budget Allocation by Subsystem Category (ICE Platform)

## 10. Safety Philosophy and Culture

Safety is not merely a regulatory checkbox in FSAE; it is a professional and ethical obligation. The vehicles operate in close proximity to other competitors, track workers, and spectators. A culture of safety must permeate every aspect of the team's operations, from workshop practices (mandatory safety glasses, no open-toed shoes, hot-work permits) to design decisions (appropriate safety factors, redundant safety systems) and testing protocols (designated safety personnel, fire extinguishers on-site, driver extraction practice).

For electric vehicles, the safety requirements are significantly more stringent due to the presence of high-voltage systems, typically operating at 300–600 volts DC. The accumulator (battery pack) must be designed with multiple layers of protection, including a Battery Management System (BMS) with cell-level voltage and temperature monitoring, an Insulation Monitoring Device (IMD), a Brake System Plausibility Device (BSPD), and a comprehensive shutdown circuit that can de-energize the tractive system in response to any detected fault condition. The team must demonstrate mastery of high-voltage safety procedures and carry appropriate personal protective equipment (PPE) rated for the system voltage. Fig. 10. illustrates the architecture of the EV shutdown circuit. The team must

demonstrate mastery of high-voltage safety procedures and carry appropriate personal protective equipment (PPE) rated for the system voltage.

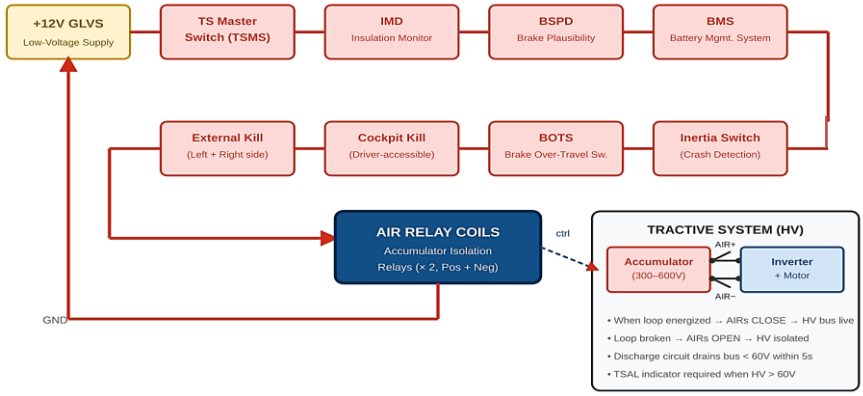



Fig. 10.: Proposed workflow: Multiscale data-driven system architecture.

## 11. Implementation and Fabrication

The implementation and fabrication phase represents the transition from theoretical design to a fully realized physical vehicle, requiring disciplined coordination across all subsystems. Once the design freeze is established and the decision matrices are finalized, fabrication activities must follow a structured workflow to ensure dimensional accuracy, manufacturability, and subsystem compatibility. As illustrated in Figure 11, the recommended fabrication workflow progresses through material preparation, jig and fixture setup, subsystem-level manufacturing, intermediate quality inspections, and final assembly integration. This staged approach minimizes rework, reduces timeline risk, and ensures that each subsystem is validated before being incorporated into the full vehicle.

During fabrication, critical components such as the chassis, suspension hardpoints, uprights, wiring harness, and cooling system must be produced with strict adherence to the tolerances defined during the CAD and FEA stages. Welding fixtures and alignment jigs should be used to maintain geometric accuracy, particularly for the frame and suspension pickup points, where small deviations can significantly affect vehicle dynamics. Intermediate inspections—such as tube notching verification, weld penetration checks, and dimensional conformity assessments—should be documented throughout the process to maintain traceability and quality assurance.

Subsystem integration should follow a bottom-up sequence, beginning with the rolling chassis, followed by drivetrain installation, electrical system routing, and final bodywork and aerodynamic components. This incremental integration strategy, reflected in the workflow of Figure 11., allows the team to identify interface issues early and resolve them before full assembly. By adhering to a structured implementation methodology, teams can significantly improve reliability, reduce assembly errors, and increase the likelihood of passing technical inspection on the first attempt.

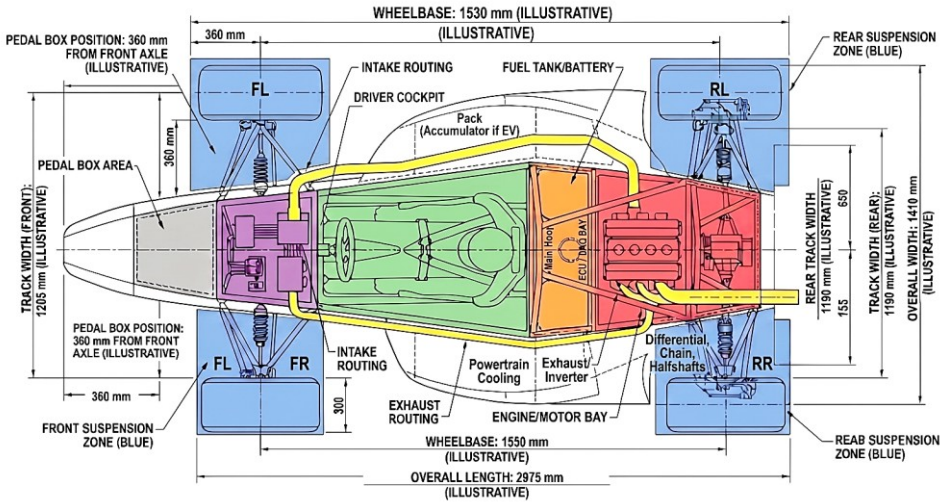



Fig. 11.: Formula SAE Car Layout - Top-Down Technical Schematic.

## 12. Conclusion

The Formula SAE project stands as one of the most demanding and rewarding capstone engineering experiences available in higher education. This paper has presented a comprehensive framework organized around five critical pillars: strict rulebook adherence, systems engineering integration, disciplined project management, design for manufacturability and reliability, and rigorous testing and validation. The evidence from decades of FSAE competition history consistently supports the same conclusion: the teams that win is not necessarily those with the most advanced or lightest cars, but those that build reliable, well-tested vehicles and prepare their drivers and presenters thoroughly for every event.

The tables, flowcharts, and decision frameworks presented in this paper are intended as practical tools that teams can directly adopt or adapt to their specific programs. Whether pursuing an ICE or EV platform, the fundamental principles remain the same: understand your constraints (the rulebook), design as an integrated system, manage your time ruthlessly, build what you can manufacture, and test relentlessly. A car that runs reliably will always outperform one that sits in the paddock, no matter how beautiful it looks on paper.

While this comprehensive framework provides a robust roadmap for Formula SAE success, several limitations must be acknowledged regarding its universal applicability. First, the framework's workflows—particularly those involving extensive simulation-to-validation correlation and multi-stage physical testing—assume a baseline level of financial and infrastructural resources that may be unattainable for first-year or highly resource-constrained programs. For such teams, strict adherence to these rigorous validation protocols may need to be heavily scaled down to align with their realistic manufacturing and budgetary constraints. Furthermore, while the core philosophy of rulebook

compliance is universal, the specific architectural and safety examples discussed are primarily influenced by the North American SAE rulebook. Teams competing internationally must carefully adapt this framework to account for regional regulatory variations, such as the distinct structural, electrical, and autonomous requirements mandated by the Formula Student Germany (FSG) regulations. Finally, the framework relies on a baseline of institutional support for knowledge transfer and mentorship, a variable that remains highly volatile and difficult to standardize across different university environments.

Future work in this area could explore quantitative correlations between testing hours and competition placement, develop standardized knowledge transfer frameworks for student organizations, and investigate the application of model-based systems engineering (MBSE) tools to the FSAE design process.

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