PROJECT PRESENTATION

Suspension Subsystem Design

Griffin Braunreiter

Mechanical Engineering BS · Northwestern University

Graduation: June 2026

REQUIREMENTS

Problem Statement

Design a robust suspension system for a single-seater vehicle competing in the Baja SAE collegiate design series: a wheeled off-road vehicle expected to survive rock gardens, jumps, and mud pits while remaining light enough to be competitive on acceleration, maneuverability, and hill climb events.

Single-Seater Platform

Purpose-built off-road vehicle, competition ruleset

4WD Drivetrain

Suspension must package and articulate a driven front and rear axle

4-Hour Endurance Race

Jumps, logs, rocks, and ditches; sustained high-load, high-cycle terrain

Design Goals

Decrease Turning Radius

Tighten the steering envelope for maneuverability sections without sacrificing stability

Proportional Component Weight

Minimize component weight with increasing load cases

Minimize Bump Steer

Hold toe angle constant through wheel travel so the car tracks straight over rough terrain

Increase Overall Maneuverability

Increased caster and track width, neutral Ackermann, and a shorter wheelbase

REQUIREMENTS

Axle Selection

Rather than custom-building driveshafts, CV axles were sourced from proven ATV/UTV aftermarket platforms and modified to fit the build.

Articulation Angle Rating

45° outboard / 30° inboard maximum deflection angle.

Length Modification

Welded extensions to fit the target trackwidth.

Plunge Travel

Inboard joint stroke long enough to cover full suspension bump and rebound without bottoming out.

Spline Compatibility

Custom spline inserts were designed for the hubs to ensure proper mating.

Shock Selection

Air shocks were selected off-the-shelf, and the suspension geometry was designed around their envelope.

Travel

Travel matched to estimated needs, with more travel in the rear than the front.

Cost

Shocks were chosen based on cost versus added accessories.

Adjustability

Air valve for adjustable pressure.

Mounting Geometry

Upper arm and chassis mounts matched to the shocks' mounting hardware.

Timeline & Milestones

Nov 24

Design Freeze

Geometry, hardpoints, and component design locked for manufacturing

Feb 2

Rolling Chassis

All four corners assembled, aligned, and articulating on the chassis

May 1–4

Competition

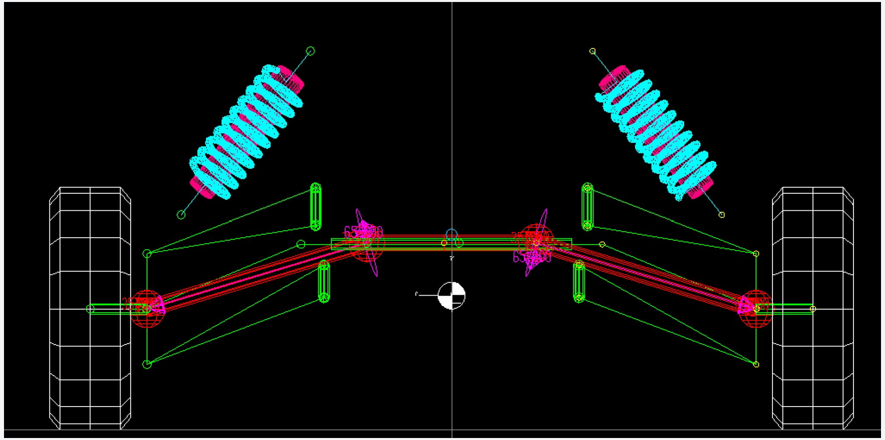
Baja SAE endurance race, dynamic events, and technical inspection

SECTION ONE

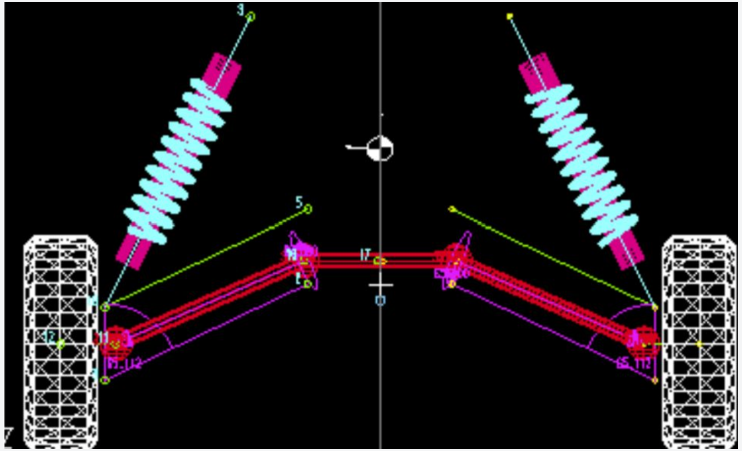
Kinematic Geometry Design

KINEMATIC DESIGN

Suspension Architecture



Front double A-arm with rack and pinion steering. Shock mounted to the upper arm. Simplest and most reliable of front suspension setups.



Rear H-arm with the shock mounted to the upright. Lightweight, robust setup, team struggled with pure trailing arm in prior years. Minimal changes necessary.

Kinematic Tools

Lotus Shark

- Bump, roll, and steer modules
- Camber, caster, and toe curve generation
- Suspension-geometry solver used for the majority of iteration

Optimum Kinematics

- Higher-fidelity multi-body geometry solver
- Cross-check of Lotus Shark outputs before hardpoints were frozen

Ackermann Steering Geometry

Positive

- Inside wheel turns more than outside wheel
- Ideal for low-speed cornering

Negative

- Outside wheel turns more than inside wheel
- Ideal for high-speed cornering

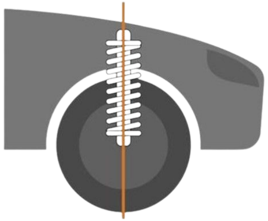
Neutral

- Wheels turn the same amount
- Balance between high and low-speed maneuverability

Caster

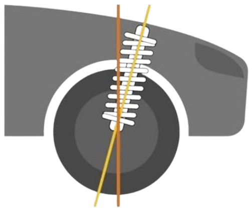
Neutral

- Steer axis perpendicular to ground
- Low steering effort
- Relatively stable



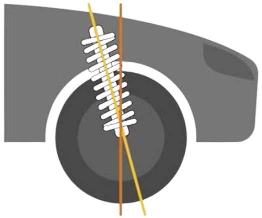
Negative

- Steering axis tilted forwards
- Extremely low steering effort
- Unstable



Positive

- Steering axis tilted backwards
- Returning force on wheels
- Higher steering effort, but more stable

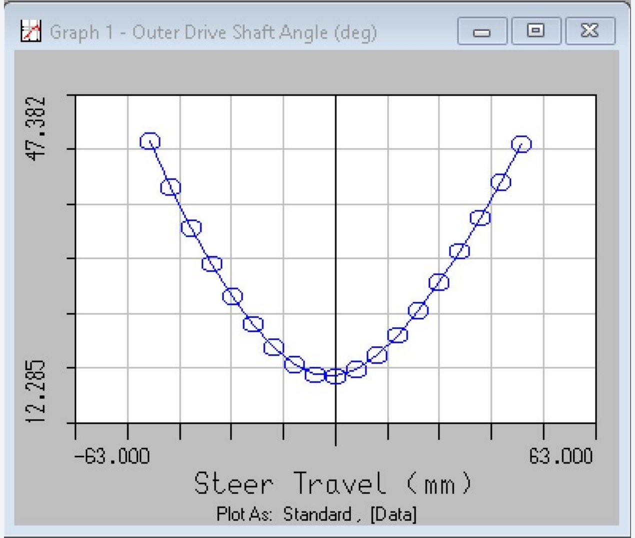


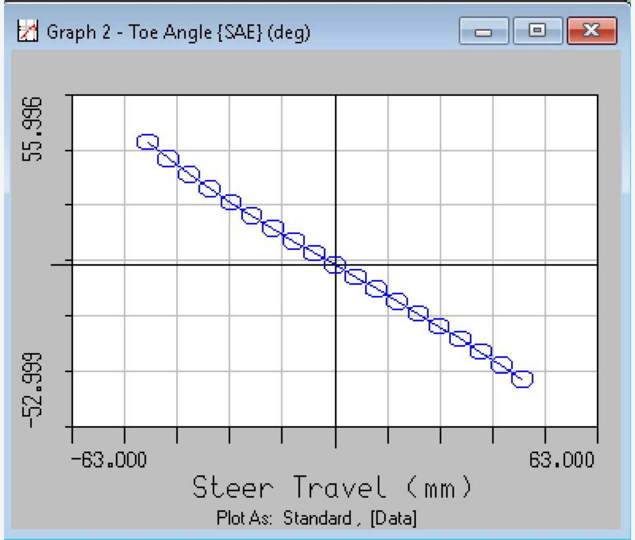
Turning Radius vs. CV Joints

- Turning radius depends on your steering toe.
- 4WD vehicles cannot get as much toe as 2WD vehicles due to the axles.
- Maximize steering toe while staying within the allowable deflection angle of the outboard joint

< 45^{O}

Working outboard CV angle through entire steering range





Trackwidth and Wheelbase

Wider Trackwidth

- The width of the vehicle wheel to wheel
- Improves side-to-side stability and cornering grip

Shorten Wheelbase

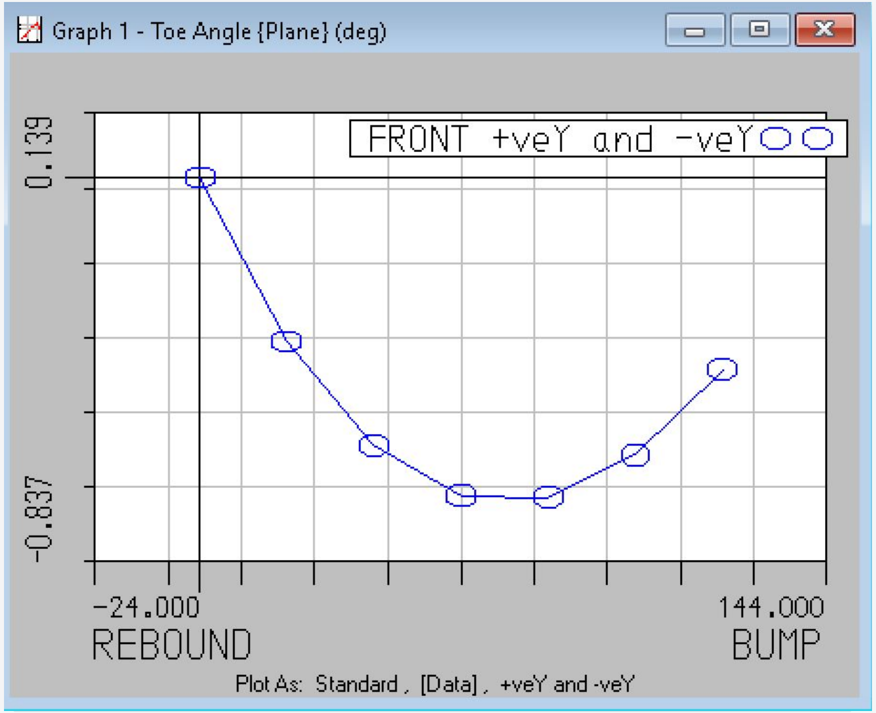
- The length of the vehicle wheel to wheel
- Decreases front-to-back stability and turning radius
- Harder overall packaging

Bump Steer

The amount that the wheels turn through the entire suspension travel. Decreases straight line stability over rough terrain.

< 1°

Target toe change across the working wheel travel range



Final Geometry

-7% to -14%
Ackermann Range

-0.49°
Bump Steer

40.18° / 37.2°
Steering Toe

9.8°
Caster

60.75"
Wheelbase

61.75"
Trackwidth

SECTION TWO

From Design to Build

COMPONENT DESIGN

CAD/CAM Workflow

01

Skeleton Sketch

SolidWorks skeleton sketch defines every hardpoint

02

SolidWorks CAD

Components modeled around geometry

03

SolidWorks FEA

Components proofed through FEA cases

04

NX Siemens CAM

Toolpaths programmed for final aluminum parts

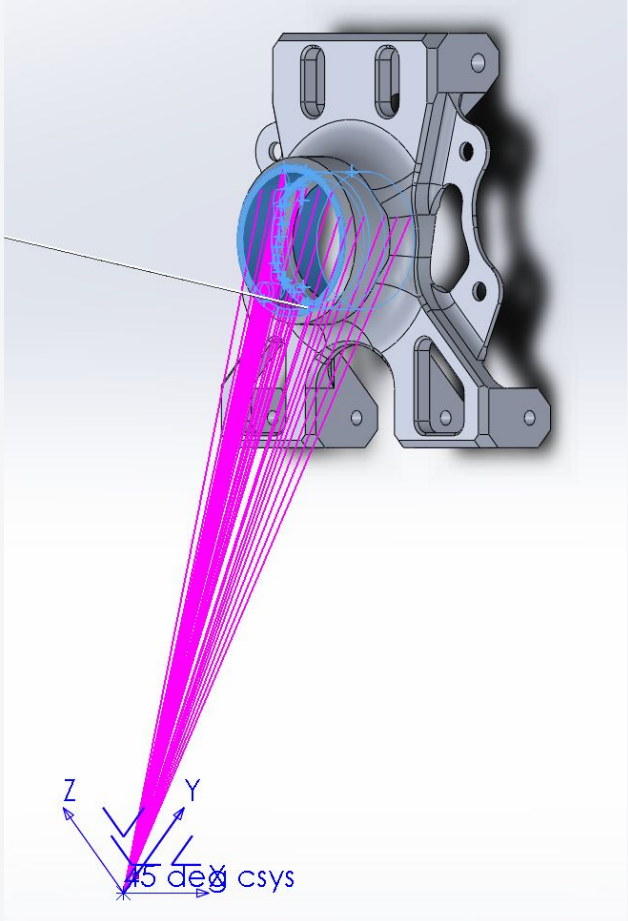
FEA Load Cases

All components undergo FEA evaluations. Load cases are based on the estimated weight change from the previous year's vehicle coupled with a 5G shock load. Due to high load variability and the possibility of overloading, we design to a minimum yield FOS of 1.2.

318kg*5Gs*9.81m/s^2 = 15600N for all components

Yield vs Ultimate FOS

As a general rule, the team designs to the yield FOS for all components. This allows for a safer, more conservative design.



Steel Control Arm Welding

Control arms were fabricated from steel tube, cut and bent professionally, but welded in-house.

01

Fixture & Jig

Tubes held at exact hardpoint locations by 3D printed fixtures

02

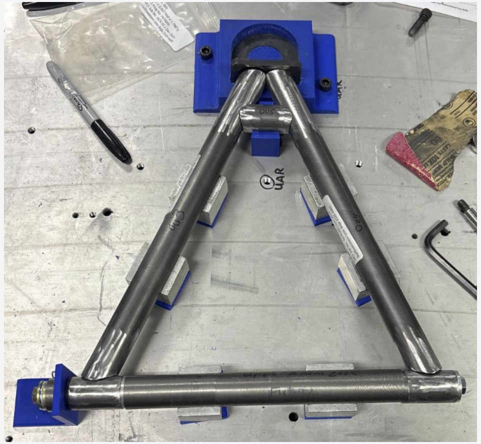
TIG Weld

Full-penetration TIG welds at gusseted joints for the best strength-to-weight on thin-wall tube

03

Inspect & Verify

Post-weld dimensional check against the CAD, plus visual inspection of every joint



MANUFACTURING

CNC Machining

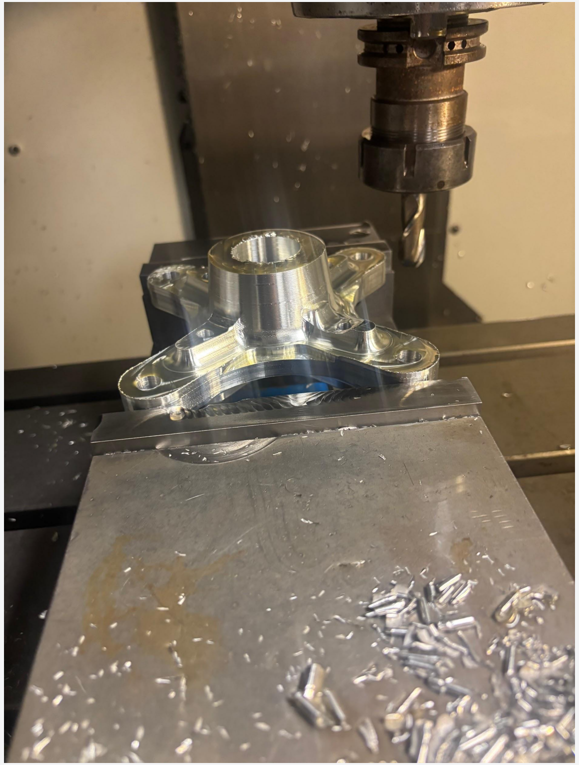
Aluminum uprights and hubs were machined in-house by their designers before final assembly onto the chassis.

Haas Super Mini Mill & VF2

3-axis CNC milling for uprights and hubs

Competition Spares

Each unique part has a spare made prior to competition



Testing

Terrain Testing	Incline stability, rollover test, and jump test at an ATV park
Repeatable Testing Plan	Braking and turning radius trials on both dirt and pavement
Try to Break it	The car is pushed to its limit to ensure the team has enough time to make changes

Results

Turning Radius	Average radius decreased from 12.5ft to 9ft at slow speed
Competition Events	34/69 in Suspension & Traction; 41/69 in Endurance; DNF in Maneuverability
No Suspension Failures	Suspension carried the car through competition without a failure

Future Improvements

Every design needs to end somewhere. These are the changes we'd carry into the next iteration now that another full season exists to design against.

Custom Axles

Move beyond the stock CVs toward a joint rated for a wider angle

Improved DAQ for Load Cases

IMU or wheel force transducer logging across all four corners

Coilover Shocks

Move towards coilover shocks which provide more adjustability and allow for softer suspension setups

Assembly FEA

Run assembly FEA cases to improve component interaction studies

CLOSING

Lessons Learned

Everything take time

From design to ordering to manufacturing and assembly, everything needs to be accounted for in the timeline

Everything needs to be manufactured and assembled

Tool reach and component clearances drive design almost as much as kinematics

It is impossible to evaluate every case

Suspension components go through such a varied set of loading scenarios, it is infeasible to test all of them