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Suspension design

TTR9 ????????

> [name= : / /7~9][color=#d904ed] TTR7 TTR8
> TTR9 TTR9
> ((...)
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Iterative Development

6 8 IC

EV

Design Changes: Motivation and Direction

Issues in Last Year's Suspension and Vehicle Dynamics System and Their Causes:

- During trail braking, inside rear wheel lift was observed.
  - The center of gravity (CG) was positioned incorrectly (too far forward), so during trail braking the load transferred forward and toward the outside wheel, resulting in insufficient normal force on the inside rear wheel and causing wheel lift.
- Low predictability of vehicle dynamics
  - The suspension data calculations were not well established, and the suspension parameters deviated from typical values without supporting validation data.
  - Suspension geometry designed for different tire sizes was reused, resulting in relatively large roll center movement during vehicle roll, which may lead to non-

linear roll moment generation.

- Front wing ground contact under heavy braking
    - Given our vehicle's CG position and suspension setup, load transfer during heavy braking caused front suspension compression exceeding the front wing ground clearance.

Design Objectives and Rationale for This Year:

- Adjusting the center of gravity (CG) position
    - Design direction: shift the CG rearward and lower it
    - Maximizing total grip: lowering CG height directly reduces load transfer, allowing more even load distribution across all four tires by utilizing tire nonlinearity, improving cornering limits and resolving rear wheel lift under heavy braking
    - Improving handling stability: a lower CG reduces brake dive and acceleration squat; combined with mass centralization, it reduces roll inertia and pitch inertia, allowing quicker recovery and more precise response near the handling limit
- Establishing a more complete suspension data calculation process
    - A solid theoretical foundation and predictable vehicle dynamics come from a well-structured calculation and derivation process
    - To avoid repeating the dynamic issues of the 8th generation suspension, a new suspension data calculation workflow was developed from scratch
- Reasonable suspension parameter selection
    - During the design of the 9th generation car, due to time constraints, no additional simulation was conducted for suspension parameter tuning; therefore, typical reference values were adopted for parameter setup
- Optimization of suspension kinematic behavior
    - Good vehicle dynamics predictability requires not only a solid calculation process and reasonable parameter selection, but also well-designed suspension geometry
    - The following aspects of suspension kinematics were specifically considered:
        - Roll center movement: during vehicle motion, especially during roll, the vertical displacement of the roll center is closely monitored. Smaller displacement indicates smaller variation in the distance between CG and RC, resulting in more linear roll moment generation and closer alignment with theoretical behavior
        - Camber recover: in all vehicle states, we aim to maintain optimal tire grip conditions. These conditions include temperature, humidity, and contact patch. From a geometric perspective, we can control the contact patch. Ideally, at maximum roll angle, the outer wheel camber should be close to 0 degrees. However, since the tire is not a rigid body and to avoid tire rollover under peak lateral force, the geometry is designed with a maximum camber of approximately -0.5 degrees. Final fine-tuning is carried out through real vehicle testing by observing tire wear conditions
        - Anti-geometry: this mainly affects vehicle pitch behavior. During longitudinal load transfer, additional anti-geometry is required to suppress pitch angle due

        - to factors such as aerodynamic center of pressure (CoP) and front wing ground contact
        - Motion ratio (Installation ratio) curve: due to the presence of aerodynamic components, downforce increases with speed. Therefore, the heave motion ratio curve is designed to be progressive rather than linear, which helps maintain ride height and vehicle stability at high speed. For the roll motion ratio curve, symmetry and linearity between left and right turns are emphasized to ensure consistent suspension behavior
- Optimization of stiffness-to-weight ratio of suspension components
    - A well-designed structural stiffness reduces deviation between actual suspension/steering behavior and theoretical kinematics, improving vehicle dynamics predictability
    - Benefits of reducing total vehicle mass (sprung + unsprung):
        - Improved power-to-weight ratio and acceleration/braking performance: reducing sprung mass reduces total vehicle weight, directly improving acceleration performance and shortening braking distance
        - Reduced load transfer: lower total mass reduces dynamic load transfer during cornering and pitch motion, allowing more even tire loading and increasing total grip
    - Benefits of reducing unsprung mass:
        - Maximizing mechanical grip: reduced unsprung mass lowers inertia, allowing the tire to follow road surface variations more effectively and maintain stable normal force
        - Improved dynamic response frequency: reducing moving mass increases the natural frequency of the suspension system, shortens settling time, and provides more responsive steering feedback

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Suspension System Design Process:

1.Vehicle parameter calculation and setup

I. Vehicle static parameter calculation and setup

- Vehicle overall layout adjustment and center of gravity calculation

II. Vehicle dynamic parameter calculation and setup

- Maximum G-forces and wheel loads during acceleration, braking, and cornering
- Wheel loads, roll moment, and roll moment distribution during steady-state cornering at the limit

2. Suspension system parameter calculation and setup

I. Vehicle dynamic characteristics parameter

- Total ground clearance
  - Heave motion
  - Roll motion
- Ride rate
- Wheel rate (Wheel center rate)
- Sprung mass natural frequency
- Unsprung mass natural frequency
- Body roll angle
- Roll gradient
- Roll rate

II. Suspension parameter setup

- Heave motion
  - Heave spring rate
  - Heave damping coefficient
  - Heave installation ratio (motion ratio)
- Roll motion
  - Roll spring rate
  - Roll damping coefficient
  - Roll installation ratio (motion ratio)

3.Suspension geometry design and optimization

I. Front view

- Scrub radius
- King pin inclination
- Roll camber recover
- Roll center movement

II. Side view

- Caster angle
- Caster trail (mechanical trail)
- Pitch angle
- Pitch center height
- Anti-geometry
  - Anti-dive

  - Anti-squat
  - Anti-lift

III. Rocker system

- Heave installation ratio curve
- Roll installation ratio curve

4.Suspension component design and optimization

I. FEA- Stress analysis & Fatigue analysis II. Topology- Optimized stiffness-to-weight ratio III. Component lightweighting

5.3D print functional check & prototype

I. Interference check during actuation

6.Vehicle fabrication

7.Vehicle testing and theory validation

I. Functional Check

- Verified proper operation of steering, braking, and suspension systems
- Checked for interference and abnormal actuation in all mechanisms

II. Static Inspection

- Measured suspension geometry (camber, toe, ride height)
- Verified vehicle weight and weight distribution
- Inspected structural integrity and assembly quality

III. Dynamic Testing

- Conducted straight-line acceleration and braking tests
- Evaluated low-speed handling (skidpad / slalom)
- Assessed high-speed stability and steering response

IV. Data Acquisition & Analysis

- Collected data on vehicle speed, acceleration, steering angle, and damper travel
- Analyzed discrepancies between vehicle behavior and design targets

V. Feedback & Iteration

- Adjusted setup parameters (damping, weight distribution, tire pressure)
- Performed design modifications when necessary

Suspension typical spec

> [name=[illegible] :[illegible] /[illegible] /7~9[illegible]][color=#d904ed] [illegible] TTR7[illegible] TTR8 [illegible] TTR9[illegible]
> [illegible] ([illegible] spec sheet)

Vehicle dimension

1. wheelbase(unit: mm):

- [illegible] 1525[illegible] 1525 ~ 1600[illegible] :
    - [illegible] 1525 ~ 1535
    - [illegible] 1550 ~ 1580
    - [illegible] 1650[illegible]
- wheelbase [illegible] weight distribution [illegible] 1525 [illegible]
- [illegible] FSAE(FS) [illegible]

2. track width(unit: mm):

- [illegible] 75% [illegible] 1100 ~ 1300[illegible] :
    - [illegible] 1100 ~ 1150
    - [illegible] 1200 ~ 1300
- [illegible] wheelbase [illegible] 75 ~ 80%[illegible] roll moment [illegible] Roll over [illegible]
- [illegible] track width [illegible] Roll stiffness disturbance[illegible] oversteer [illegible] understeer [illegible] FSAE(FS) [illegible] 20 ~ 50 [illegible]

3. CoG height(unit: mm):

- [illegible] FSAE(FS) [illegible] 220 ~ 320 [illegible]:
  - T1[illegible] 220 ~ 280[illegible]
  - T2[illegible] 280 ~ 320
  - [illegible] 350[illegible]
- [illegible] roll over [illegible] weight transfer [illegible] FSAE(FS) [illegible]

4. Weight distribution(unit: %)

- [illegible] 45:55 ~ 50:50[illegible]:
  - 40:60[illegible] FSAE(FS) [illegible]
  - 45:55 ~ 48:52[illegible] FSAE(FS) [illegible]
  - 50:50 [illegible]
  - [illegible] 50%[illegible]
  - [illegible] (1.0 ~ 1.5 G) [illegible] pitch over [illegible] brake test [illegible]

Suspension parameters

1. Tire&Rim size(unit?Radius:inch, width:mm)

- [illegible] 8 inch[illegible] 10 inch[illegible] 13 inch [illegible]:
- **10 inch[illegible]**
  - [illegible]
  - [illegible]
  - [illegible]
  - [illegible]

- ◦ [illegible] contact patch [illegible] (R20)[illegible] 13 inch [illegible] 15 ~ 20% [illegible]
  - [illegible]
  - [illegible]
- **13 inch**[illegible]
  - [illegible]
  - [illegible]
  - [illegible]
  - [illegible]
  - [illegible] contact patch [illegible] (R20) [illegible] 10 inch [illegible] 15 ~ 20% [illegible]
  - [illegible]
  - [illegible]
- [illegible] 10 inch [illegible] 13 inch [illegible] 15 ~ 20% [illegible]
- [illegible] FSAE(FS) [illegible] cornering stiffness [illegible] GoodYear D2704, D2773 [illegible] cornering stiffness [illegible]

2. suspension type and design(wheel travel)

- [illegible] 50 mm[illegible] FSAE(FS) [illegible] double wishbone ([illegible]) [illegible] pushrod[illegible] pullrod
  - [illegible] rocker [illegible] motion Ratio[illegible] progressive [illegible] damper [illegible]
  - pushrod[illegible] rocker [illegible] progressive [illegible] damper [illegible]
  - pullrod[illegible] rocker [illegible] Progressive [illegible] damper [illegible] ([illegible]) [illegible] damper [illegible] side pod [illegible] diffuser [illegible]
- motion ratio [illegible] installation ratio [illegible]
  - motion ratio [illegible] installation ratio [illegible]
  - motion ratio [illegible] wheel travel/spring travel
  - installation ratio [illegible] spring travel/wheel travel
- [illegible] installation ratio [illegible] linear [illegible] progressive [illegible]:
  - [illegible] progressive [illegible] ([illegible]) [illegible] CoP [illegible]

[illegible]
[illegible]

- [illegible] ([illegible]
) [illegible] linear [illegible]

FSAE 2026 ????????????????

???2026 ?????????????

FSAE □□□□□□

□□□□□□□□□□□□□□□ **FSAE 2026 □□□□ (Suspension System) □□□□□□□** 2026 □□□□□□□□ (Technical Inspection) □□□

1. ?????????

- □□□□ □ Formula SAE Rules 2026 v1.0□
- □□□□ □□□□□ (Suspension)□□□ (Upright)□□□□□ (Steering Components)□□□□ (Dampers/Shock Absorbers) □□□□□□ (Critical Fasteners)□

2. 2026 ??????

1. □□□□□□□ □□□□□□□□□□□□□□□ 50 mm □□□□□□□ (Usable Wheel Travel)□
2. □□□□□ □□□□□□□□ (Mounting Points) □□□□□□□□□□□□□□□□□□□□□□□□□□□
3. □□□□□ □□□□□□□ (Rod ends) □□□□ (Spherical Bearings) □□□□□□□ (Double Shear) □□□□ (Capture) □□□

□□□□□□ □□□ 2026 □□□□□□□□□□ □□□□□□ □ Rules 2026 v1.0□ **Tech** □□□□□ □ 50 mm □□□□□□□□□□

2026 ???????V.3 ?????????

[illegible] FSAE 2026 [illegible] (Tech Inspection) [illegible]

1. ???????? (V.3.1)

- **V.3.1.1** [illegible]
    - [illegible] **50 mm** [illegible]
    - [illegible] (Bump stop) [illegible]
- **V.3.1.2** [illegible]
    - [illegible]
    - [illegible] Bump Steer [illegible] (Disqualified)[illegible]
- **V.3.1.3** [illegible]
    - [illegible]
    - [illegible] (Nose) [illegible] (Sidepod) [illegible]

2. ???????? (V.3.1.4 / V.3.1.5)

- **Critical Fasteners**[illegible] T.8 [illegible]
- [illegible]
    - [illegible] (Rod ends) [illegible] (Spherical Bearings) [illegible] **(Double Shear)** [illegible]
    - [illegible] **(Captured)** [illegible]

3. ?????? (V.3.2)

- **V.3.2.4** [illegible]
    - [illegible] (Positive Steering Stops)[illegible]

[illegible] V.3 [illegible] V.3.1.1 ~ V.3.2.9[illegible] **Tech** [illegible] (Single Shear) [illegible]

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1. ???????

```
mermaid flowchart TD A[□□□□□□□□□□] --> B[□□□□□□□□□] B --> C[□□□□□□] C --> D[□□□□□□] D --> E[□□□□□□]
E --> F[□□□□□□□□□] F --> G[□□□□□□□ FEA □□] G --> H[□□□□□□□□] H --> I[Mock Tech □□]
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2. ?????????Pushrod vs Pullrod

Pushrod □ Pullrod □□

□□	□□	□□	□□□□□
□ **A** □	□□□□□□□□□□□□	□□□□□□	□□□ FSAE □□□□□
□□□ **(Pushrod)**	□□□□□□□□□□□□□	□□□□□□□□□□□	□□□□□□□□□□□

□□□□□□ □□□□□□□□□□□□□□□□□ □□□□□□ □ V.3.1.2 □□□□□□□□

?????????????????

□A □□□□□□

□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□□

1. ???? (Roll Center) ????

- □□□□ □□□□□□□□□□□ 0 ~ 30 mm□□□□□□□□□□□□□□□□

2. ???? (Camber Gain) ? ???? (Scrub Radius)

- **Camber Gain**□□□□ 25 mm □□□□□ (Bump) □□□□□ 1.0 ~ 1.5 □□ Camber □□□
- **Scrub Radius**□□□□ 0 ~ 20 mm□

3. ???? (Toe Curve) ? ???? (Bump Steer)

- □□ □□□□□□□□ (Rack) □□□□□□ Tie-rod □□□□□□□□□□ Bump Steer□

□□□□□□ □□□□□□□□□□□□ □□□□□□ □ V.3.1.2 □□□□□

??????????????? 50mm ????

□□□ Motion Ratio □□□

1. ??? (Motion Ratio) ? ???? (Wheel Rate)

- □□□□□□ □ = \frac{K_s}{MR^2}$□□□ $ □□□ 1.0 □□□

2. 50 mm ???????? (V.3.1.1)

50mm □□□□□□□

□□□□□□□□□□□□□□□□□□□ Mock Tech □□□

1. □□□□ □□□□□□□□□□□□□
2. □□□□ □□□□□□□□□□□□□□□
3. □□□□ □□□□□□□□□□□□□□□□□□□□□□□□ 50 mm□

□□□□□□ □□□□□□□□□□□□□ □□□□□□ □ V.3.1.1 50 mm Wheel Travel□

????????????Upright???????

[illegible] Upright [illegible]

1. ?? (Upright) ????

- **[illegible] (Fit)**[illegible] (Interference Fit)[illegible]

2. ???????? (V.3.1.5)

[illegible]

- **[illegible] (Double Shear)**[illegible]
- **[illegible] (Capture)**[illegible]

[illegible] [illegible] **[illegible]** [illegible] V.3.1.5 / T.8[illegible]

Mock Tech ??????????????????

Mock Tech [illegible]

1. ???????? (Checklist)

- ☐ [illegible] [illegible] >50 mm [illegible]
- ☐ [illegible] [illegible] A-arm [illegible]
- ☐ [illegible] [illegible] Positive Locking[illegible]
- ☐ [illegible] [illegible] Rod ends [illegible]

[illegible] [illegible] [illegible] [illegible] IN.16 (Reinspection)[illegible]