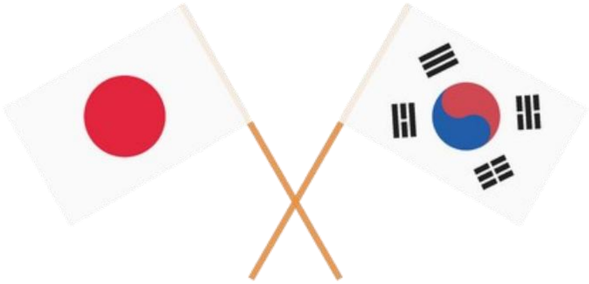
2025 IPBL

국민대학교 KOOKMIN UNIVERSITY | 자동차융합대학 COLLEGE OF AUTOMOTIVE ENGINEERING

Hiroshima Institute of Technology

KMU and HIT International Capstone Exchange Program

@ HIT, JAPAN
Feb. 9 ~ 15, 2025



@ KMU, KOREA
Feb. 16 ~ 22, 2025

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Introduction of PBL KMU-HIT

KOOKMIN RACING
HFP HIT FORMULA PROJECT
FORMULA SAE TEAM

2025/02/09 - 2025/02/15: Hiroshima Institute of Technology (HIT)
2025/02/16 - 2025/02/22: Kookmin University (KMU)

Members: 3 students (KMU) and 7 students (HIT)

- YU Jiho	（ユ ジホ 君，4年生）	
- PARK Minwoo	（パクミンウ 君，3年生）	
- KIM Jonghun	（キム ジョンフン 君，3年生）	
- 本田晴樹 君	（HONDA Haruki，4年生）	
- 實久敬郁 君	（SANEHISA Yoshifumi，3年生）	※to go to KMU
- 松本理希 君	（MATSUMOTO Riki，3年生）	
- 横野登哉 君	（YOKONO Touya，2年生）	※to go to KMU
- 坂根海七渡 君	（SAKANE Kanato, 2年生）	※to go to KMU
- 金山 雄瑠 君	（KANAYAMA Takeru, 2年生）	※to go to KMU
- 福井 雅樂 君	（FUKUI Uta, 1年生）	※to go to KMU

Introduction of Vehicle

KOOKMIN RACING
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FORMULA SAE TEAM

HIT CR-24

JSAE

Power Source: Kawasaki KX450J
Mission: Stock
ECU : FC Design
Fuel : High Octane
Length*Width*Height : 2548mm*1270mm*1214mm
Wheel Base : 1563mm
Wheel Tread: 1080mm - 1063mm
Weight (With out driver) : 191kg
Weight Distribution (With Driver): 49.1:50.9
Body Structure: Space Frame
Body Torsional Stiffness: 1,400Nm/deg

KOOKMIN RACING KF-24

KSAE

Power Source: Daelim VJF 250
Mission: Stock + Dynojet Quickshifter
ECU : Daelim Stock ECU + Dynojet Power commander V
Fuel : High Octane (Ron 100+)
Length*Width*Height : 2743mm*1310mm*1133mm
Wheel Base : 1505mm
Wheel Tread: 1200mm - 1170mm
Weight (With out driver) : 163kg
Weight Distribution (With Driver): 51:49
Body Structure: CFRP Monocoque + Rear Frame
Body Torsional Stiffness: 3,200Nm/deg

KOOKMIN RACING F-25

FORMULA SAE

Motor & Inverter : EMRAX 228 MV & CASCADIA PM100DX
Accumulator Pack: Molicel P45B 70S 6P
HV Max / Nominal Voltage: 294V / 252V
HV Max Constant Discharge Current: 272A
Length*Width*Height: 2,800mm*1,390mm*1155mm
Wheel Base: 1586mm
Wheel Tread: 1180mm - 1160mm
Final Drive Ratio: 4.09:1
Vehicle Weight (W/O) : 230kg
Weight Distribution (W/): 49.8:50.2
Body Structure: CFRP Monocoque
Body Torsional Stiffness: 5,600Nm/deg

PBL Theme (Published in Last Week PBL)

- Consider the body rigidity required for a FSAE vehicle to exhibit enough competitive dynamic performance.
- Discussion should be quantitative.
- Especially, consider the weight, cost, performance of the tires used, and course layout.
- And consider them in relation to the vehicle dynamics

HIT Formula Project Space Frame

KOOKMIN RACING Monocoque

The body design is different, but the goal is the same.

Let's find common ground across different countries, competitions, cultures, and technologies, and implement a system applicable to both teams!

Main Subject Selection

Requirements for Body Design and Manufacturing

Concept Selection
- Configuration of target specifications
- Rough packaging layout
- Target stiffness design
- Selection of design concept

Design
- Material selection
- Detailed geometry
- Detailed packaging
- Modeling and verification

Simulation
- Body-only analysis
- Full vehicle analysis
- Specimen analysis (specimen, crash)

Manufacturing
- Selection of manufacturing method
- Process design

Testing
- Body-only test
- Full vehicle test
- Specimen test

Practical Constraints
- The design of the 2025 vehicle is already completed or in the manufacturing stage, so the changes can be applied from future vehicles onward.
- Since the currently available technologies differ significantly, the focus should be on verification rather than researching detailed design aspects.
- Applying a unified design format is the most important objective.

Main Subject: Body Stiffness Design Guide

1. Vehicle Dynamics Simulation

2. Targeting Body Torsional Stiffness

3. Body Torsional Stiffness Simulation

4. Body Torsional Stiffness Test

5. Data Logging Analysis

Body Design Process of Each Team

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2025 Vehicle HIP Formula Project Body Design Process

1. The body requirements are received from the suspension team.
2. The focus is on packaging and creating a simple and lightweight vehicle.
3. Body analysis involves bending analysis, but torsional analysis is not conducted.
4. Overall vehicle analysis is not performed.
5. The vehicle is built while verifying SES.
6. Body stiffness is not measured separately.
7. During the actual test phase, measurements are taken to check the impact on some members of the space frame.

2025 KOOKMIN RACING Body Design Process

1. The target body stiffness is handed over from the suspension team (however, the current method for selecting target body stiffness is not optimal).
2. Although a target body stiffness exists, it is very difficult to design considering body stiffness due to packaging and regulations.
3. In the case of the F-25 vehicle, design could not proceed while performing the analysis.
4. In the overall vehicle analysis, the target body stiffness value was used for the analysis (therefore, actual stiffness values were unknown, leading to potential errors).
5. When manufacturing the vehicle (due to SES documentation), it was more important to build the lightest car that meets regulations rather than modifying the design to meet the target stiffness.
6. The first analysis of body stiffness was performed after the vehicle was completed, before the torsional test (until then, the body stiffness was still unknown).
7. During the actual test phase, body stiffness was not considered (as the vehicle typically had a body stiffness value greater than 3000).

-> The selection of 5 topics for the development of both teams.

1. Vehicle Dynamics Simulation
2. Targeting Body Torsional Stiffness
3. Body Torsional Stiffness Simulation
4. Body Torsional Stiffness Test
5. Data Logging Analysis

1. Vehicle Dynamics Simulation

Expected Effects of Vehicle Dynamics Simulation

1. **Verification of experiments and simulations conducted at Hiroshima University**
   1. Identifying the cause of vehicle spin when body rigidity was weak
   2. Implementing improvements in the next vehicle

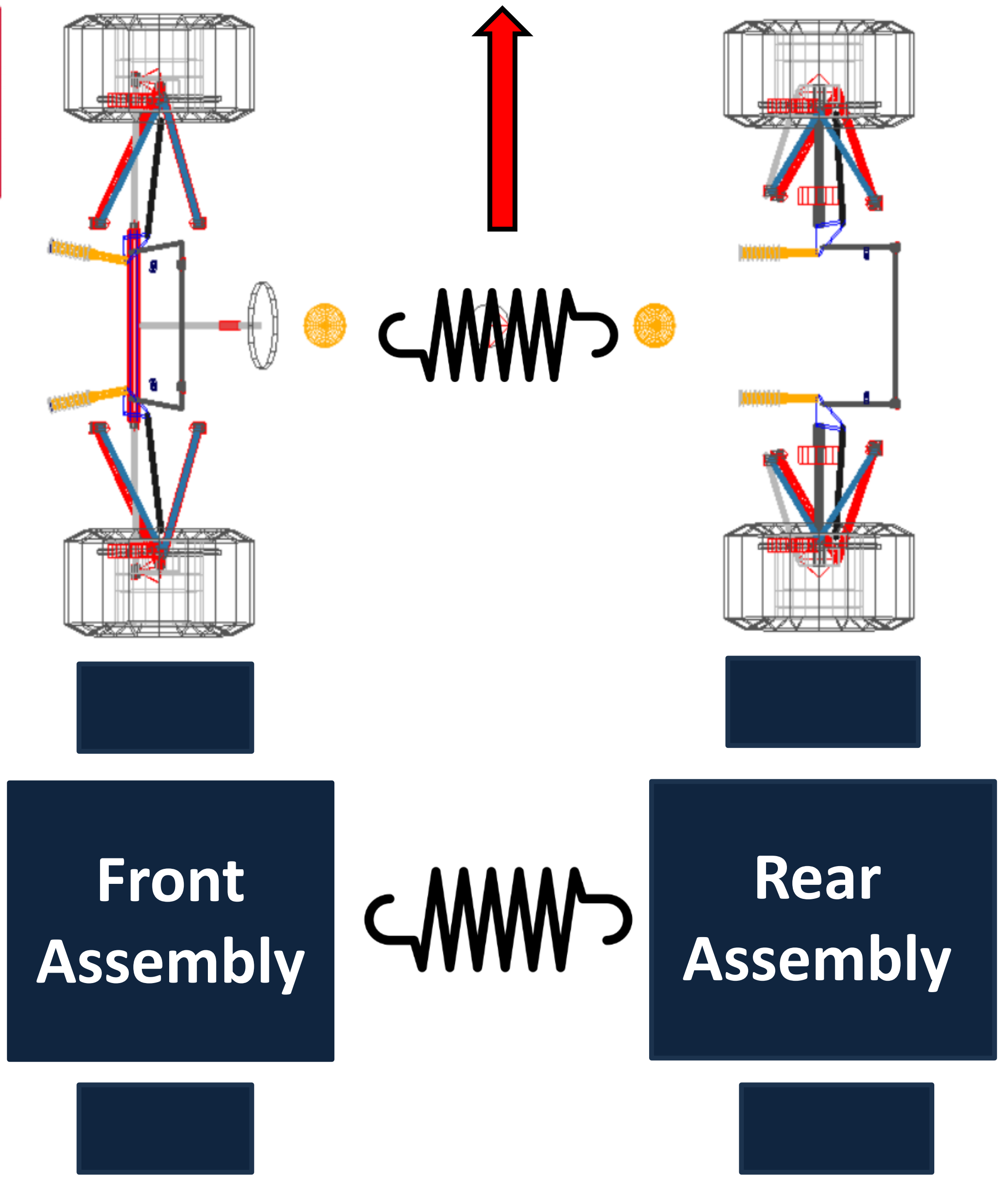
2. **Optimizing body rigidity for each vehicle**
   1. Analyzing vehicle behavior based on body rigidity (Step Steer, DLC)
   2. Simulating poor road conditions in a standardized competition environment and assessing vehicle balance maintenance (Drainage Channel)

3. **Identifying the reason for optimal body rigidity and selecting rigidity without Multi-Body Dynamics analysis**
   1. Allocating more time to other areas for further improvement

1. Vehicle Dynamics Simulation – Last Week

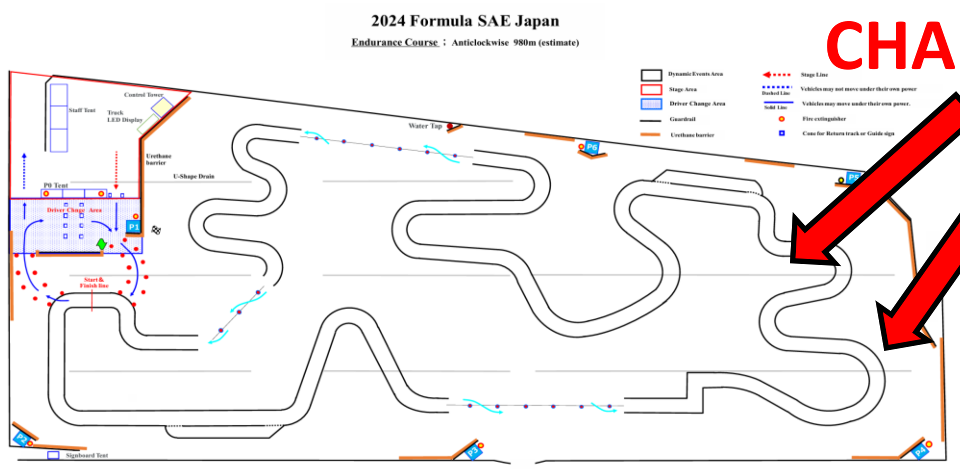
Full Vehicle Dynamics Simulation Model Setup

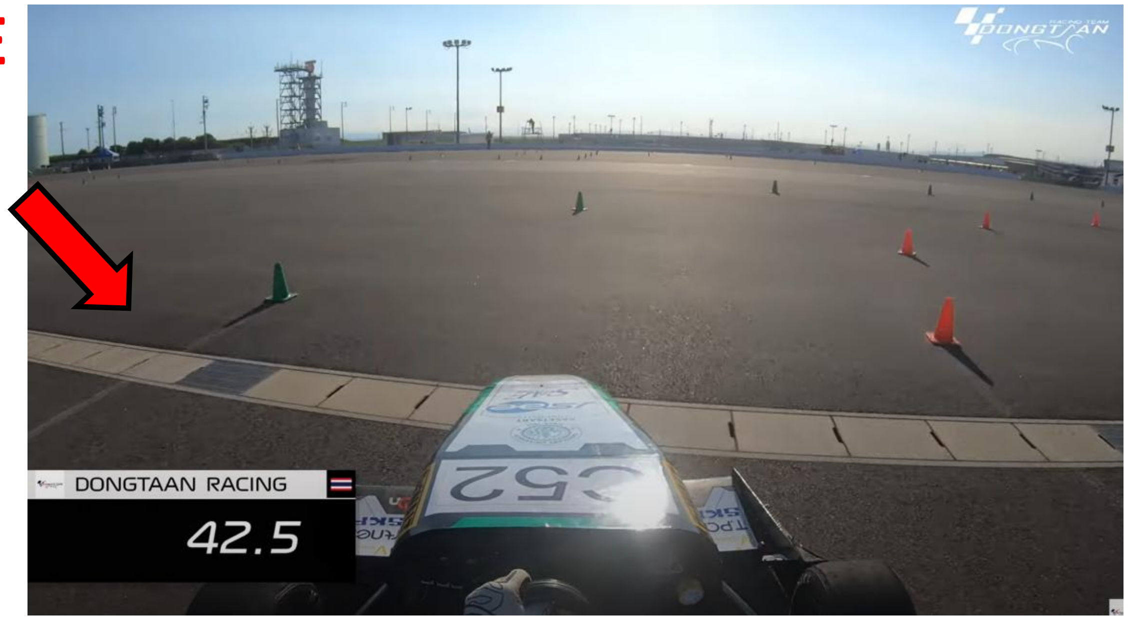
Including a 3-directional translational spring and a 3-directional torsional spring.



Competition Characteristic

DRAINAGE CHANNEL!





DRAINAGE CHANNEL!

Poor road conditions affecting vehicle stability during the endurance event

1. Vehicle Dynamics Simulation – Last Week

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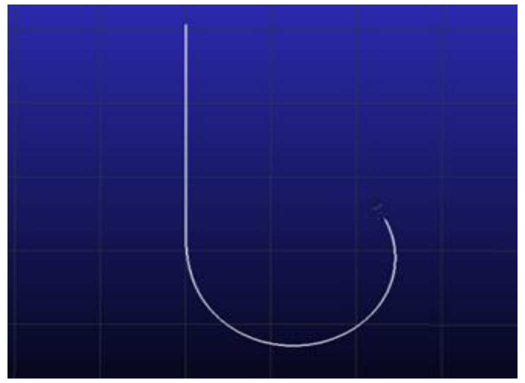
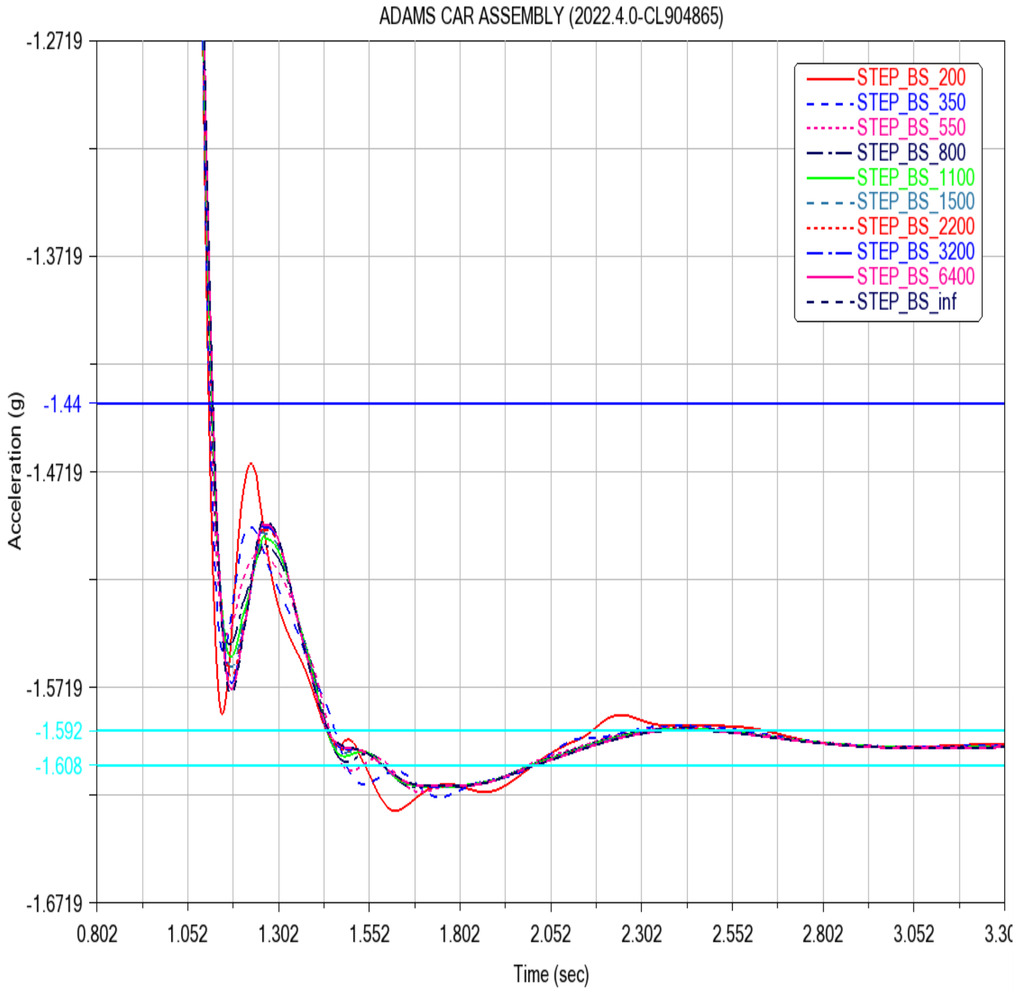
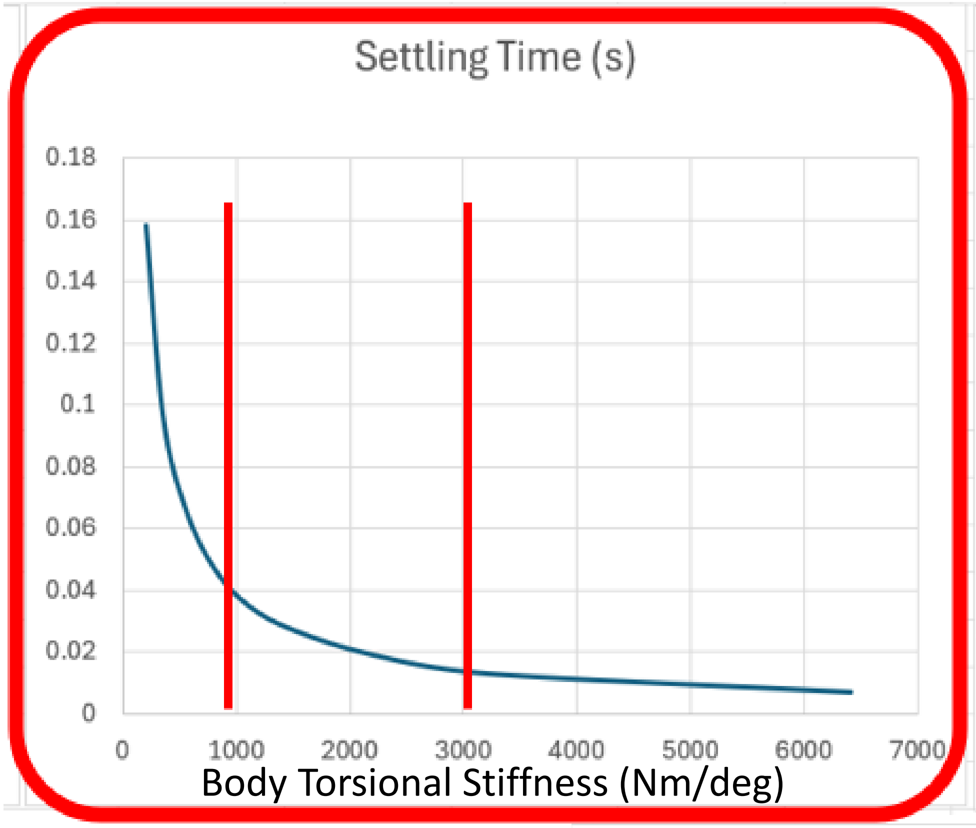
Normal State of Road Surface (KOOKMIN RACING F-25)

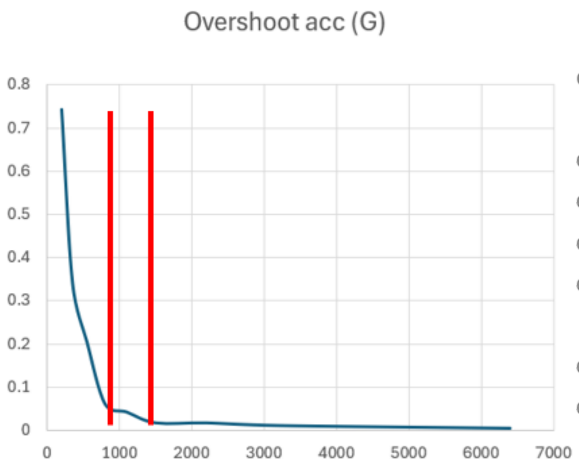
Step Steer

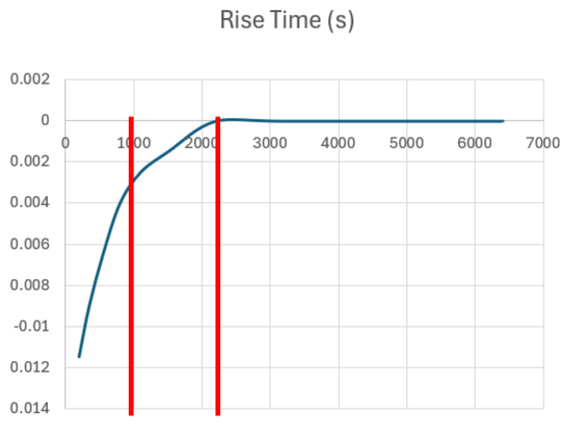
Analysis Conditions:
KOOKMIN RACING F-25
Lateral 1.6G, 0.2s of Increasing Steering Angle





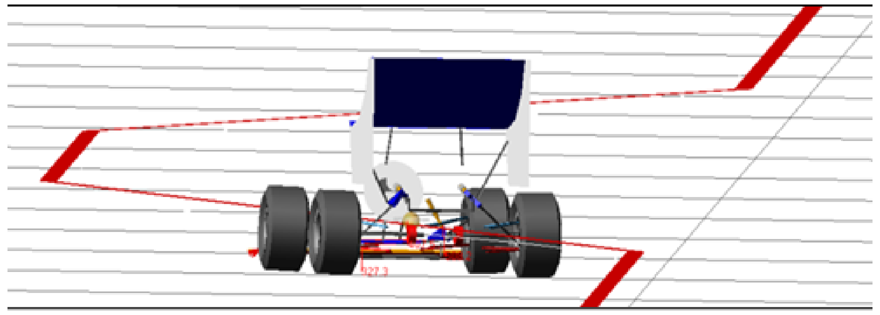


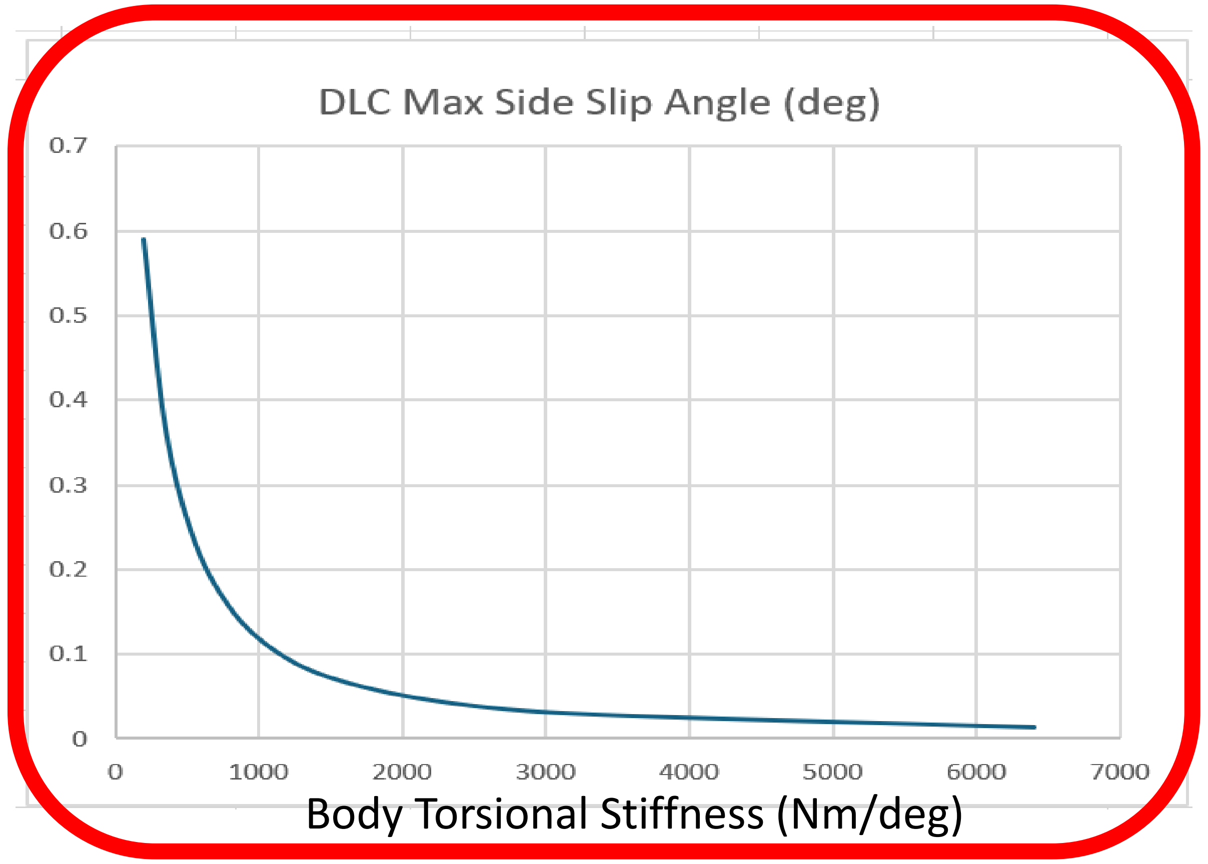


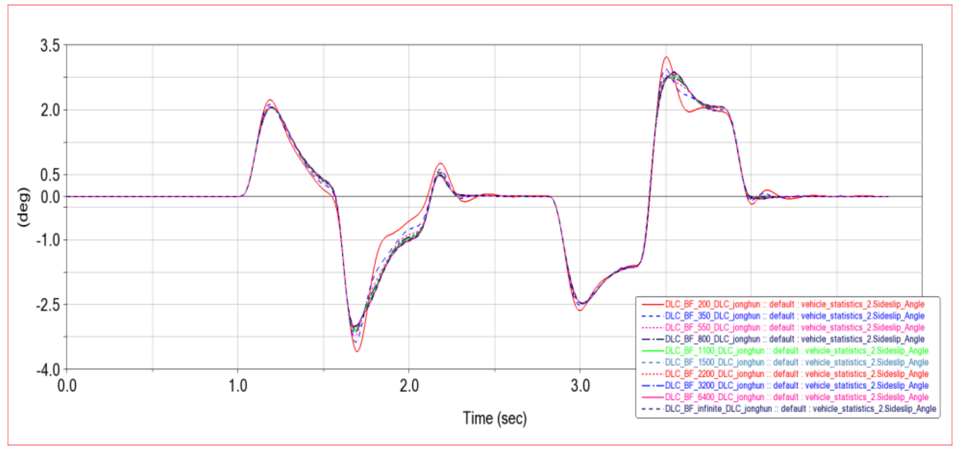


DLC(Double Lane Change)

Analysis Conditions:
KOOKMIN RACING F-25







1. Vehicle Dynamics Simulation – Last Week

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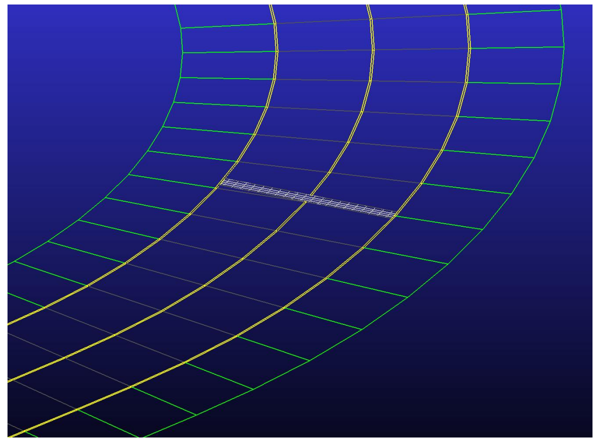
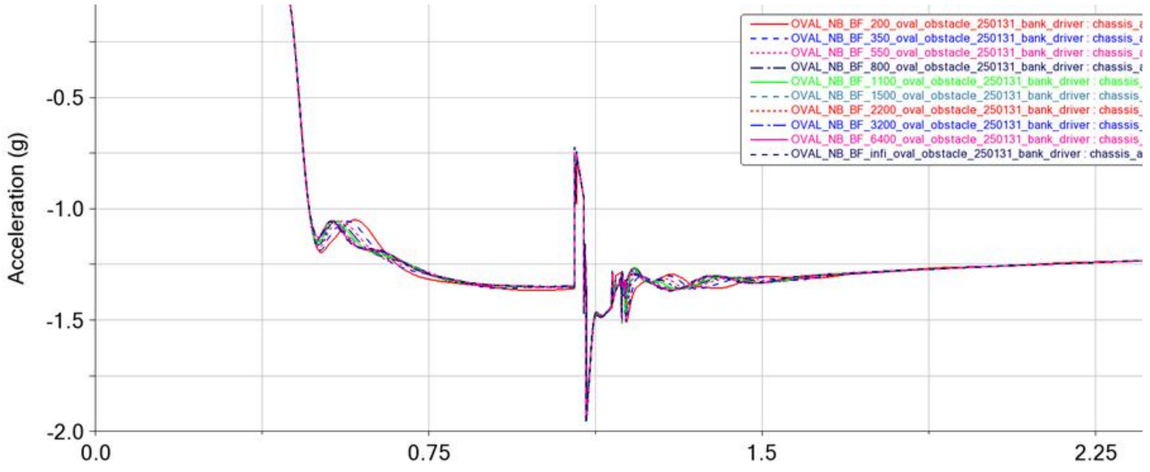
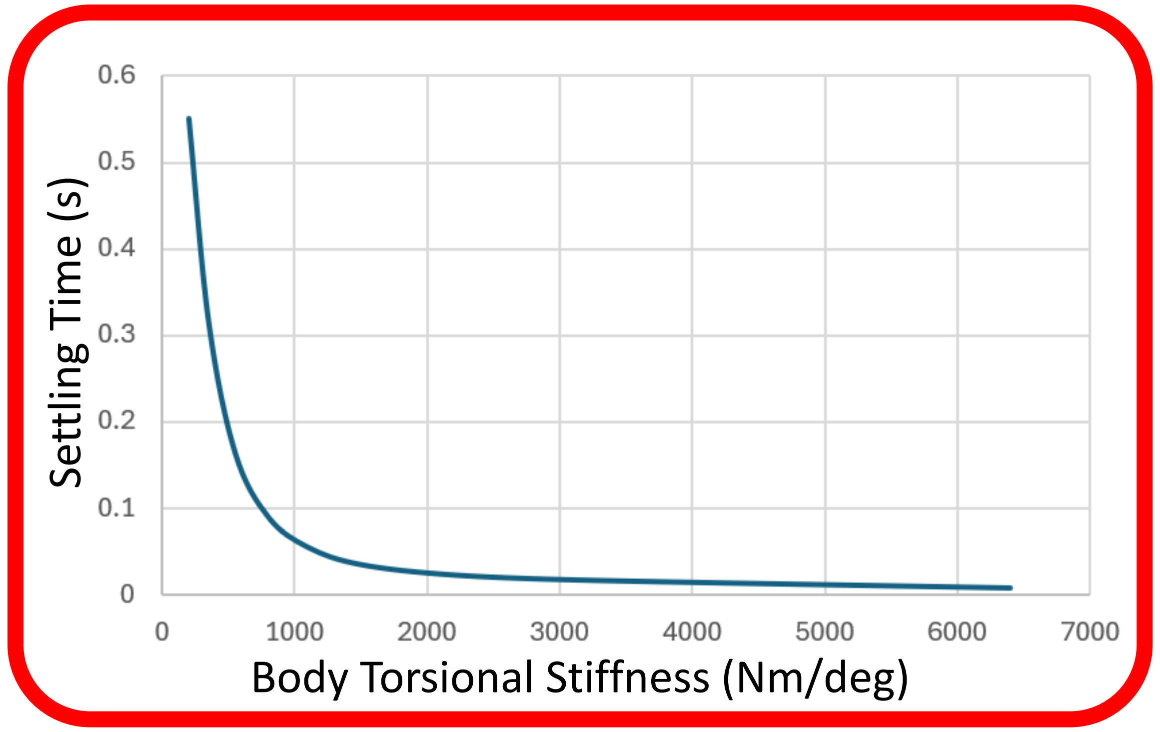
Unique State of Road Surface (KOOKMIN RACING F-25)

DRAINAGE CHANNEL

Analysis Conditions:
KOOKMIN RACING F-25

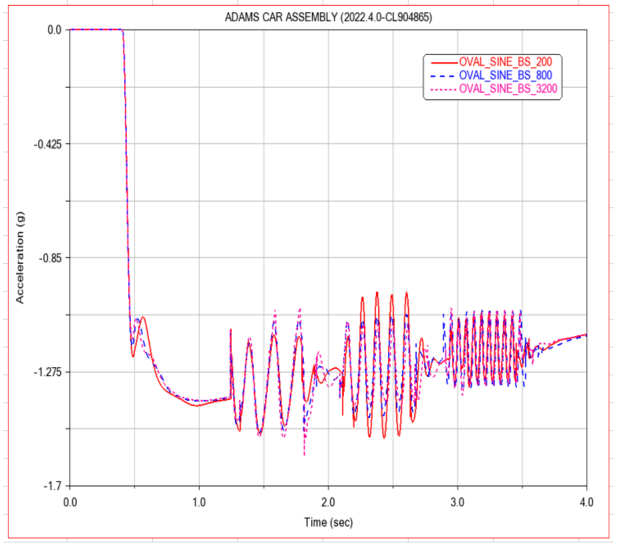


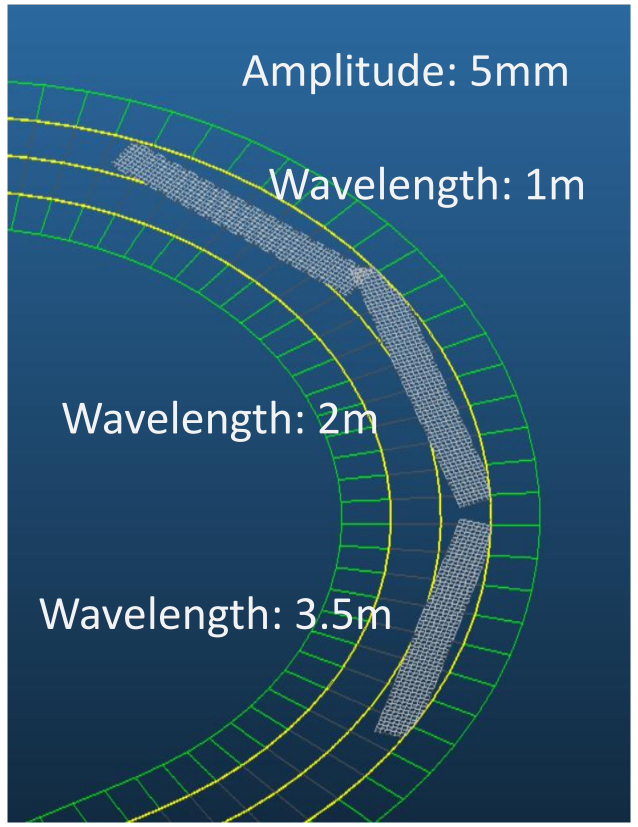




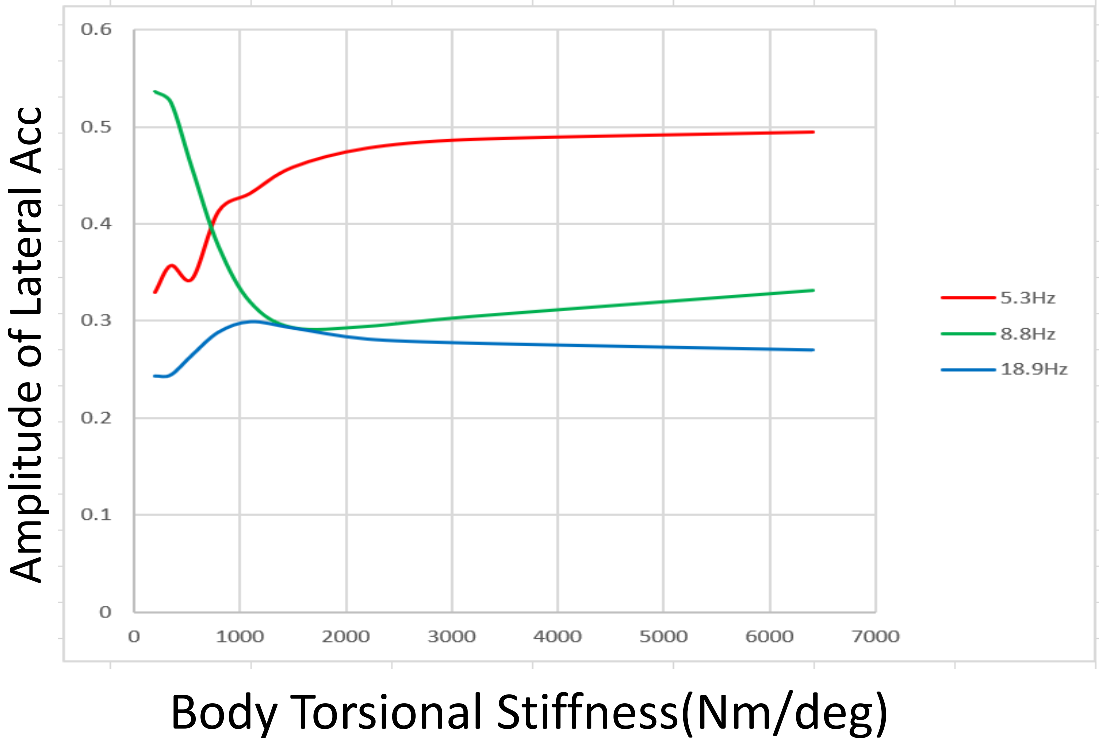
Sine Wave

Analysis Conditions:
KOOKMIN RACING F-25



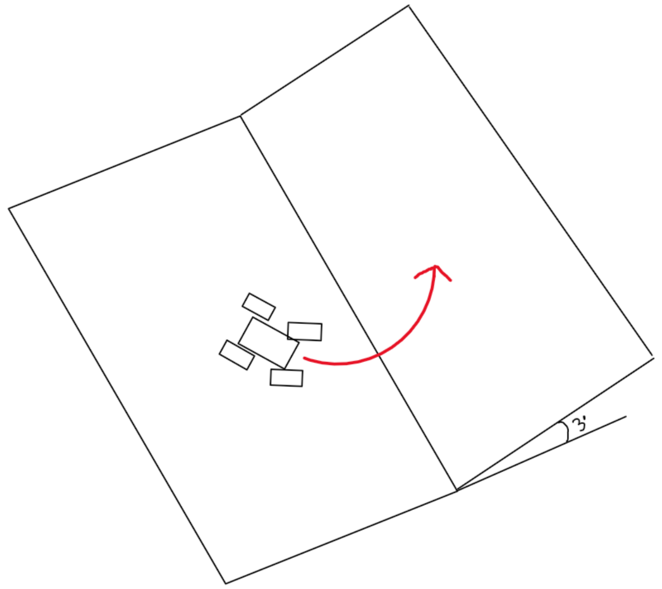


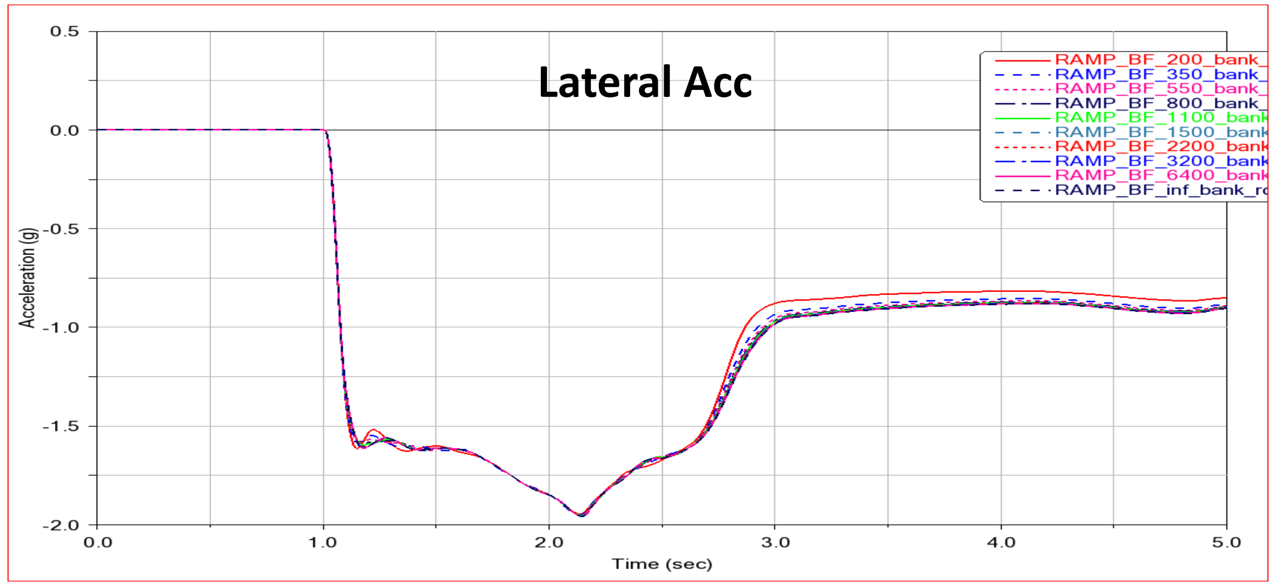
Lateral Acc

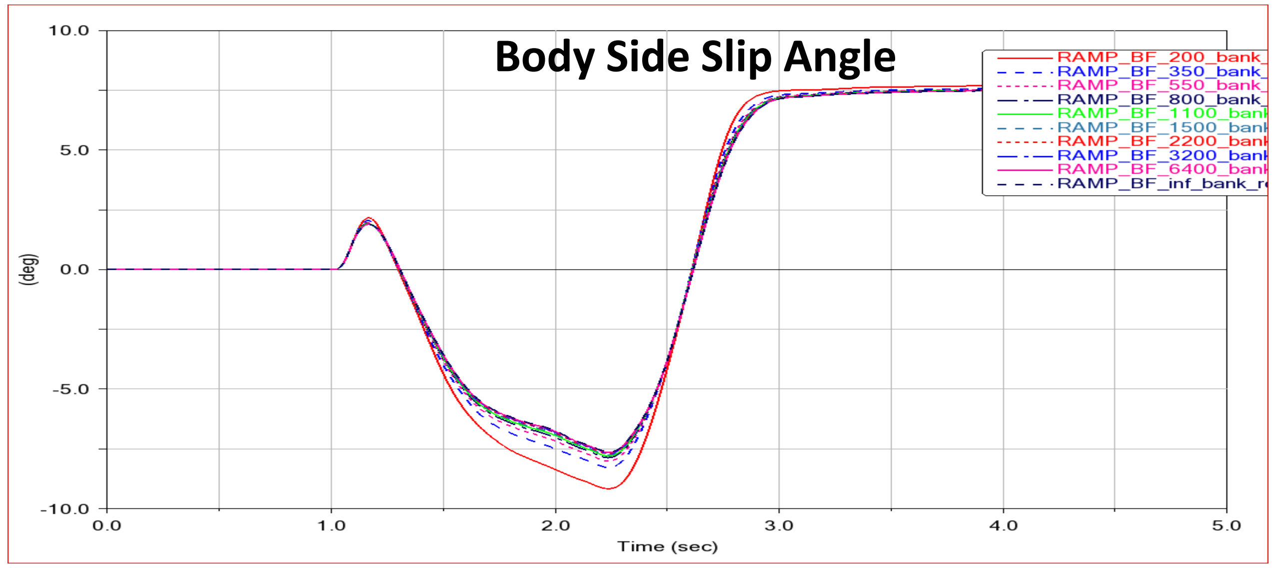


Ramp

Analysis Conditions:
KOOKMIN RACING F-25
Bank Angle: 3~5 degree







Analysis for importance of Body Stiffness in Dynamics

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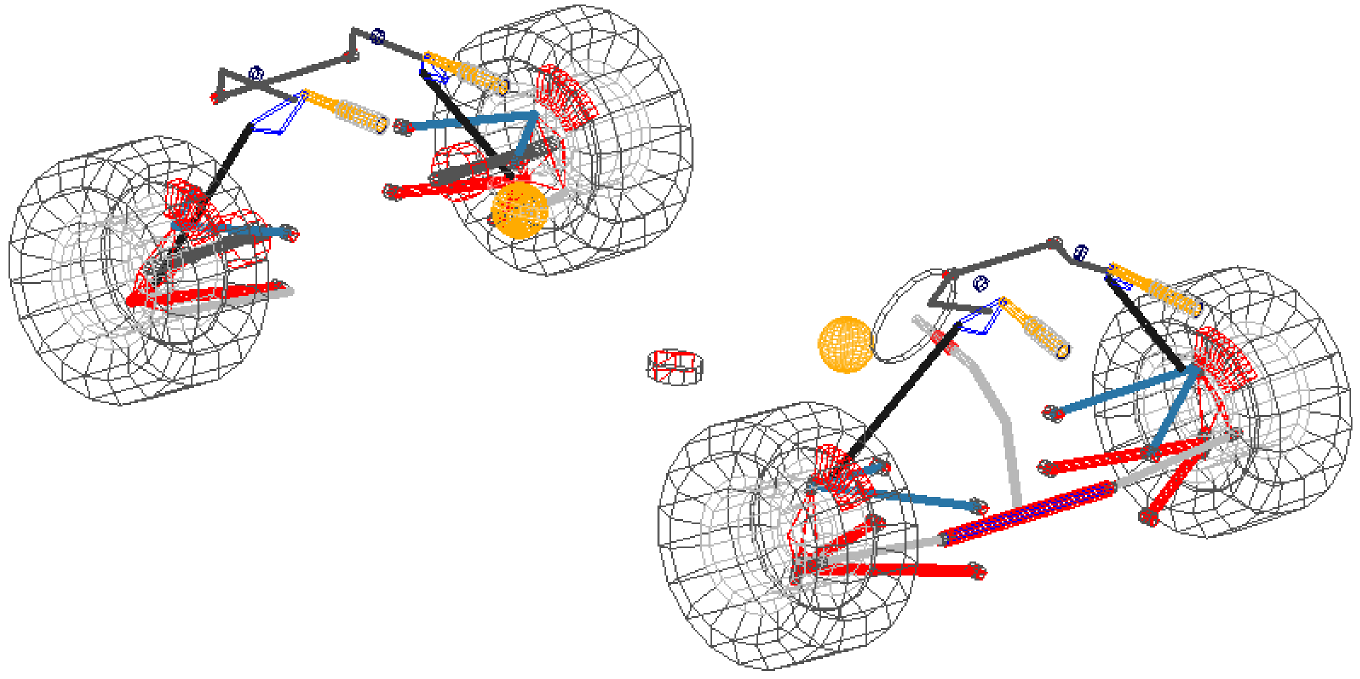
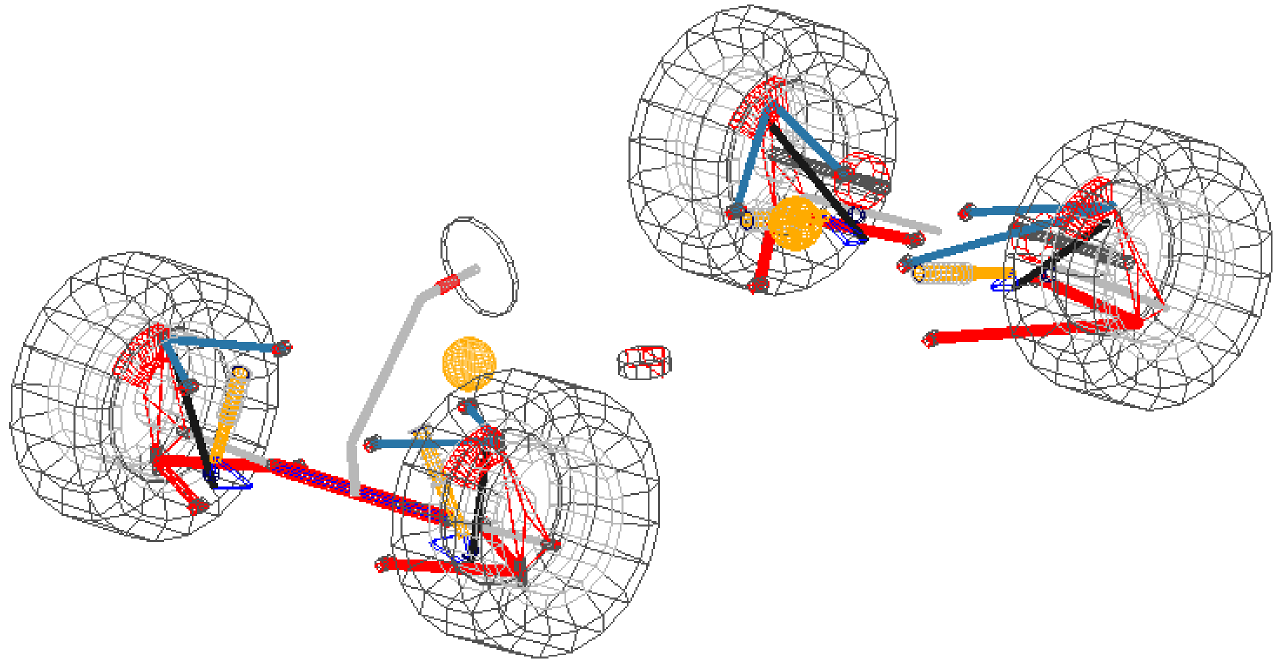
Comparison

F-25



CR-24



VS

Total Weight: 300kg
Hard suspension (Roll angle: 1deg)
The two Cgh are similar between the front and rear. (because of heavy battery)

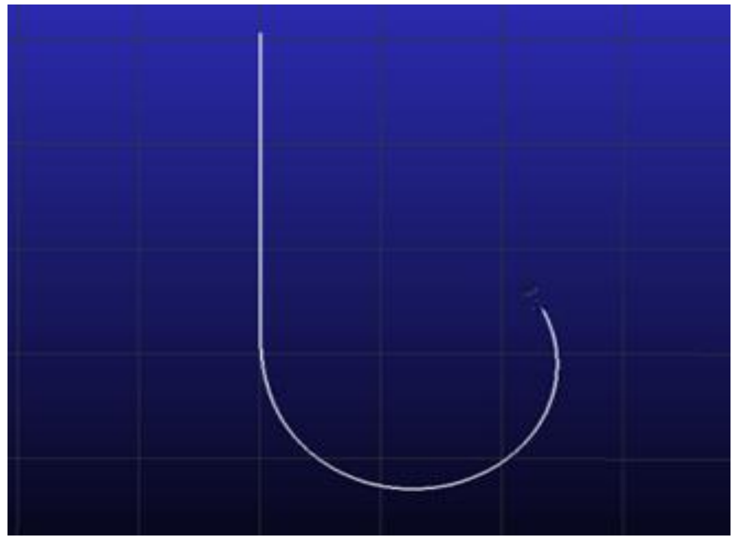
Total Weight: 253kg
Soft suspension (Roll angle: 3deg)
Rear cgh is higher than rear

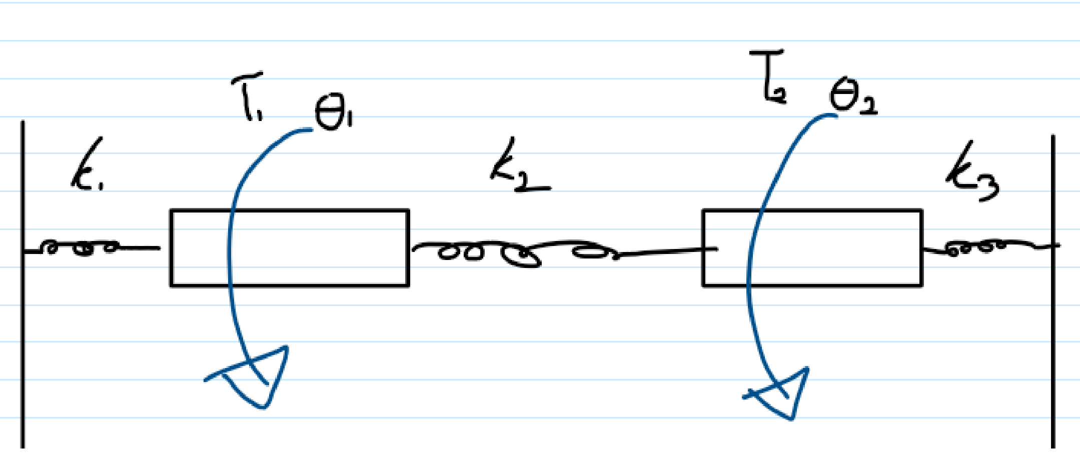
Develop a generalized body stiffness design process for Formula Student by comparing these two extreme vehicles.

Analysis for importance of Body Stiffness in Dynamics

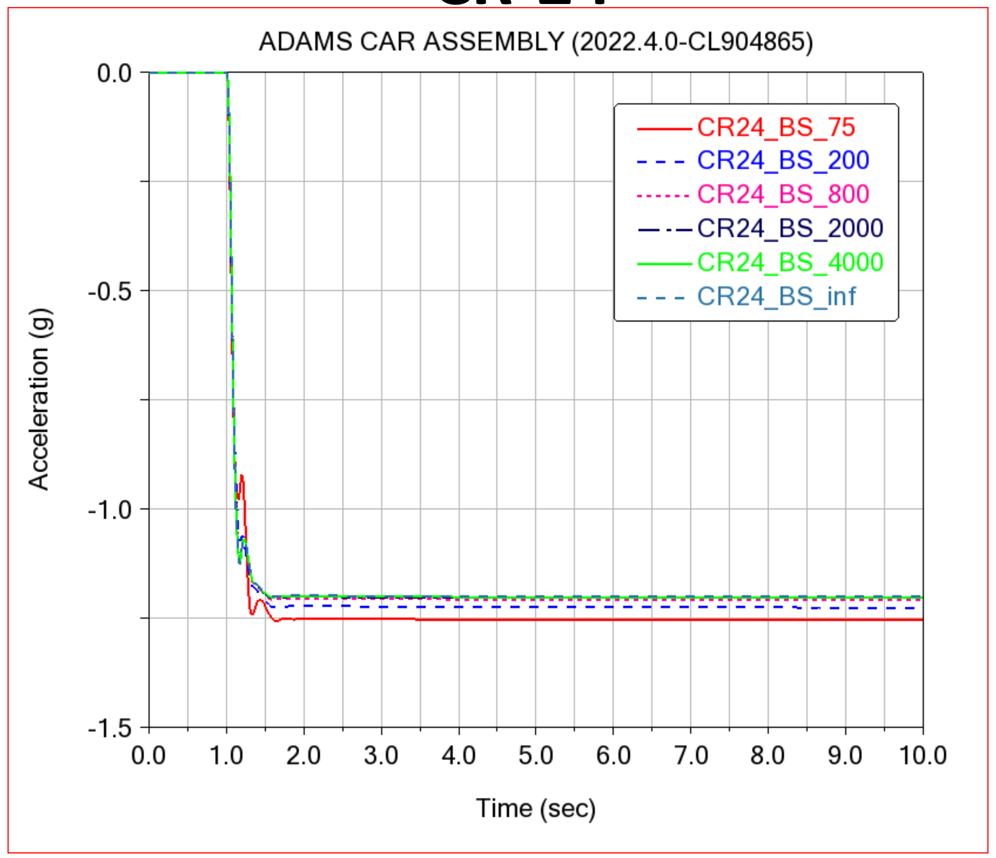
Step Steer

Analysis Conditions:
45km/h, Lateral 1.2G, 0.2s of Increasing Steering Angle

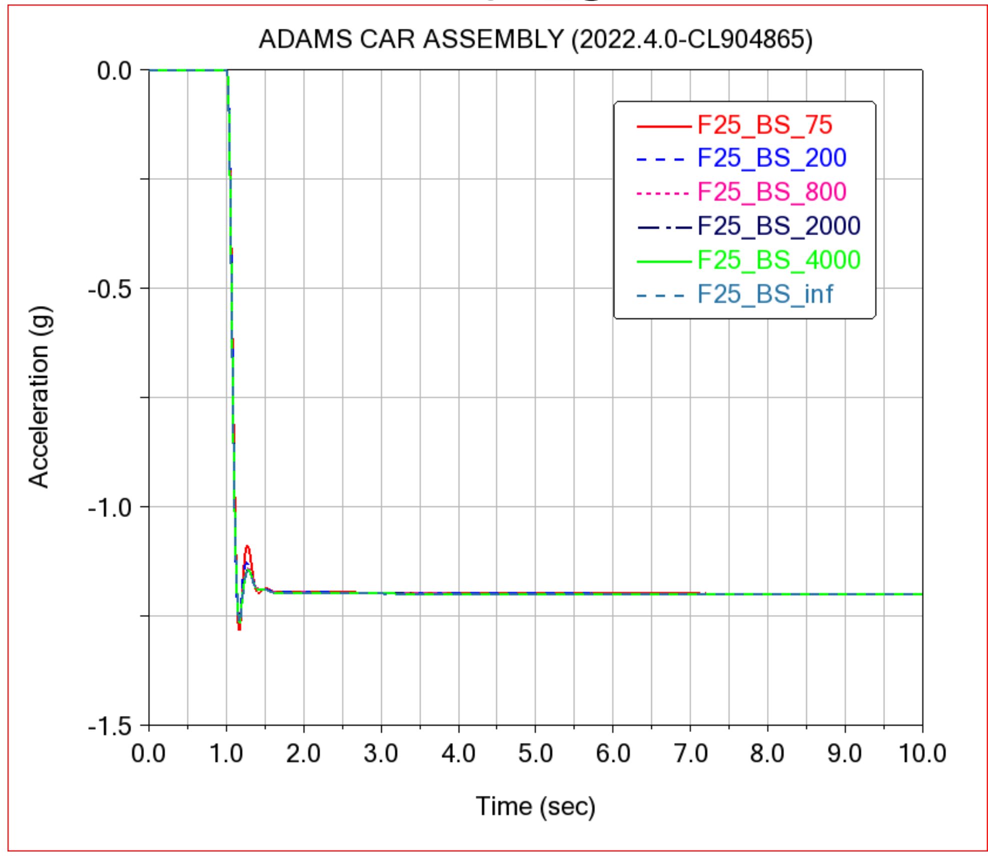




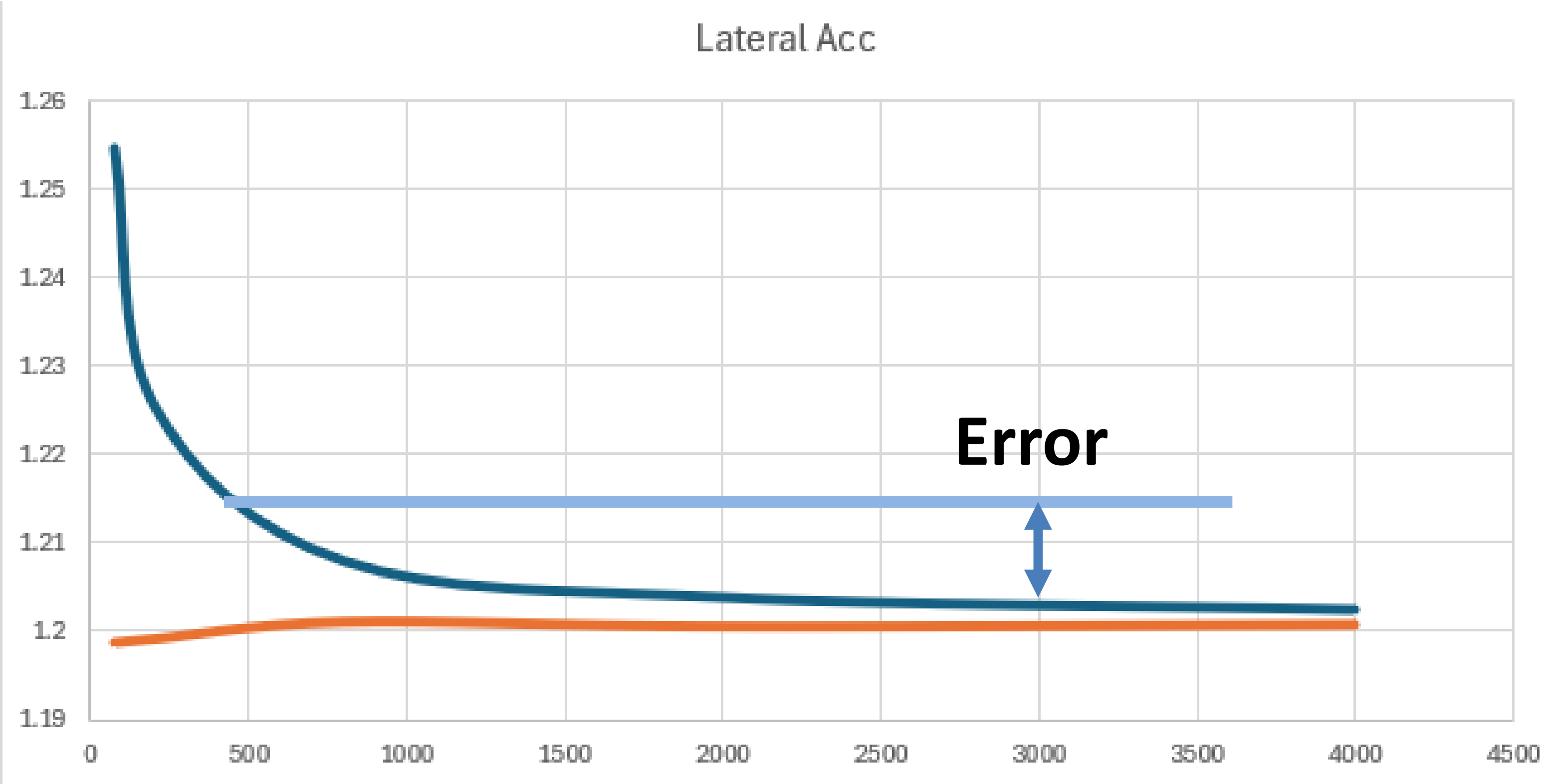
CR-24



F-25

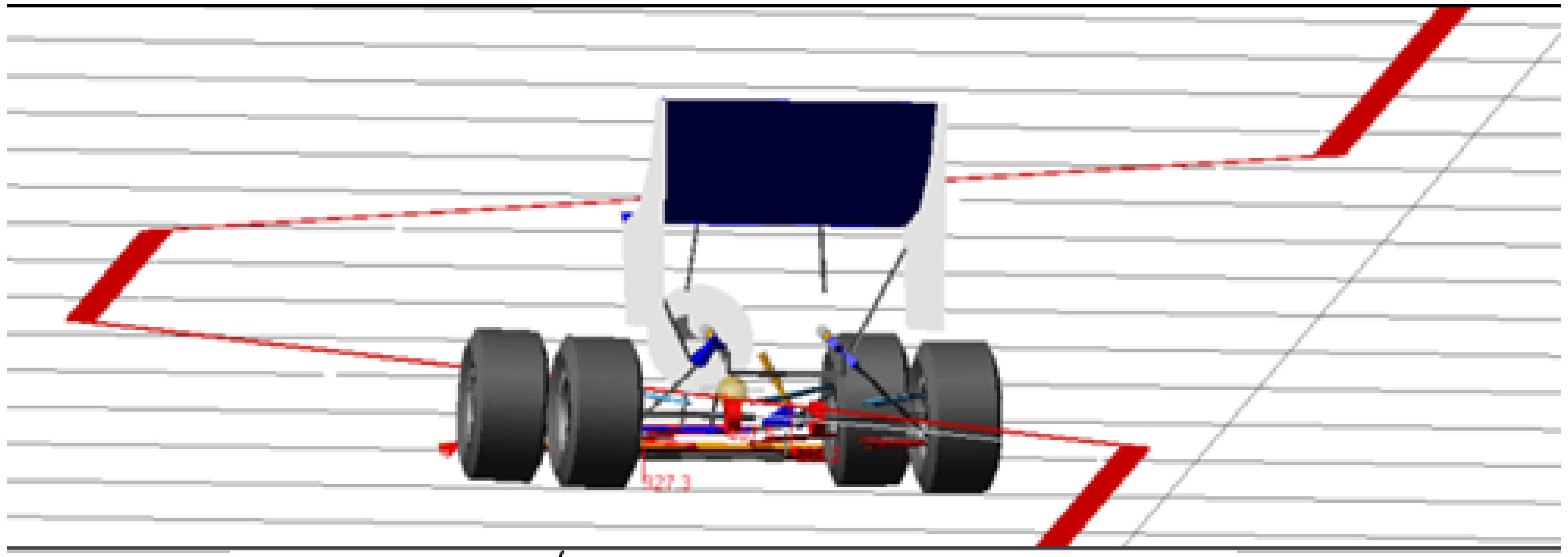


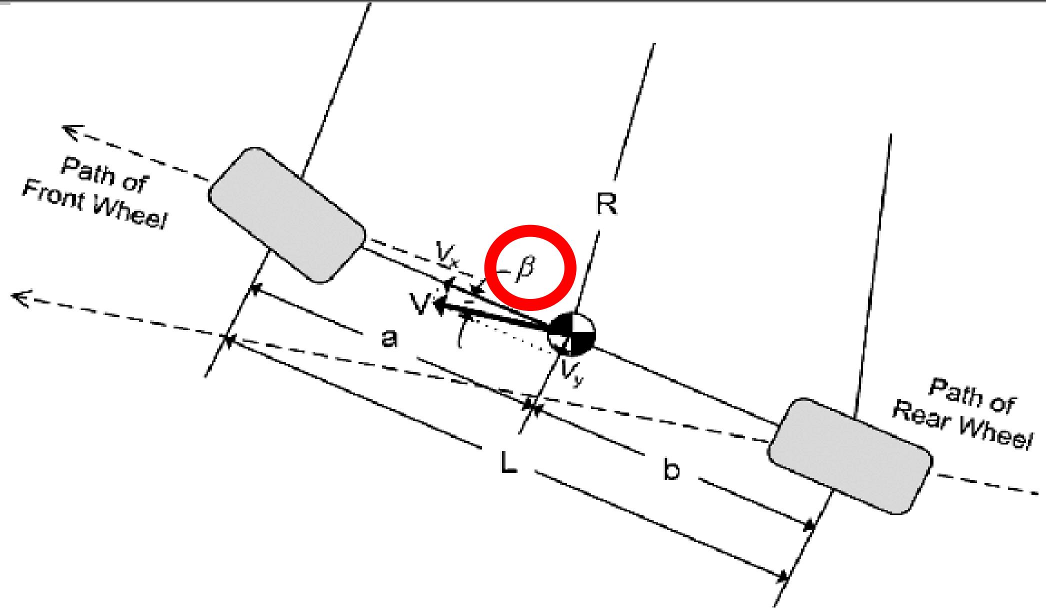
Because the difference in roll stiffness between the front and rear is large,
If the difference between K1 and K3 is big, the effect of K2 increases (roll angle).

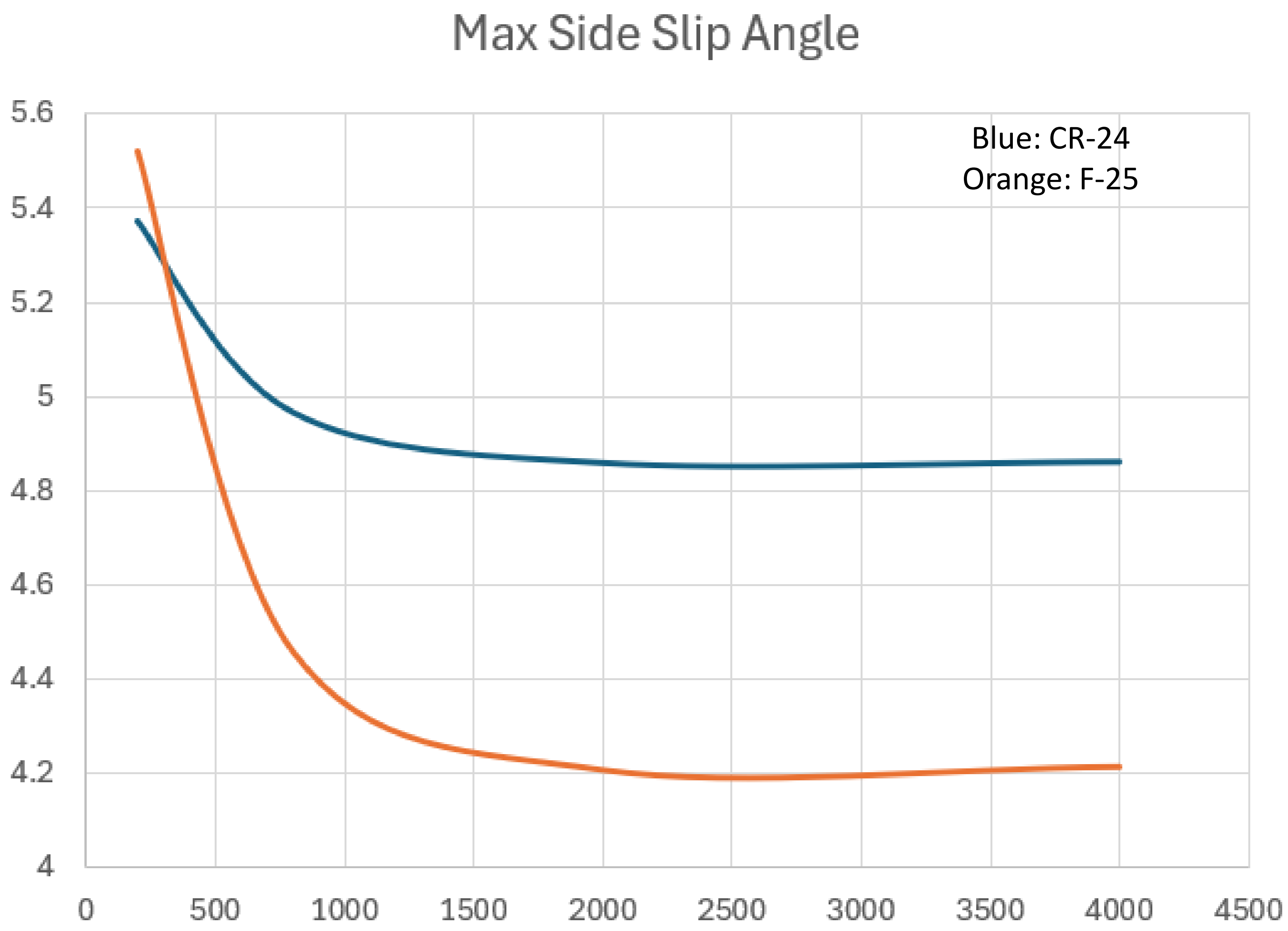


Analysis for importance of Body Stiffness in Dynamics

DLC(Double Lane Change)







The car with higher roll stiffness (F-25) has bigger changes in side slip angle.

↓

If the suspension roll stiffness is high, the body stiffness also needs to be high.

Analysis for importance of Body Stiffness in Dynamics

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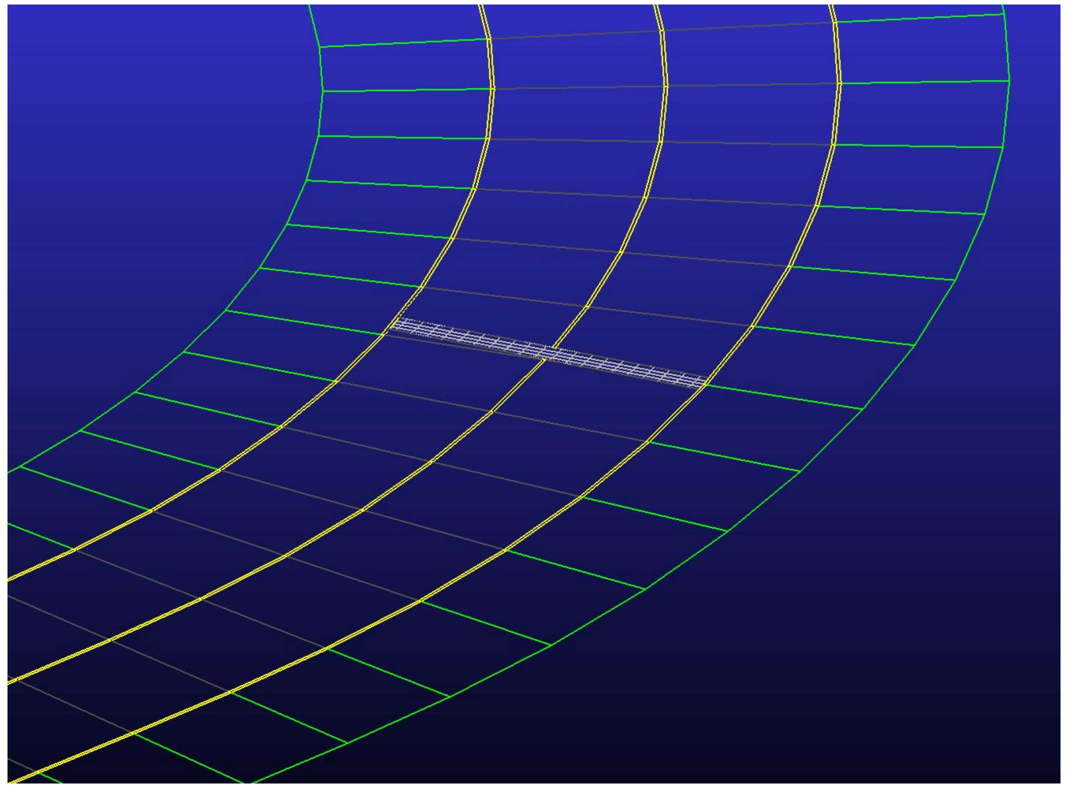
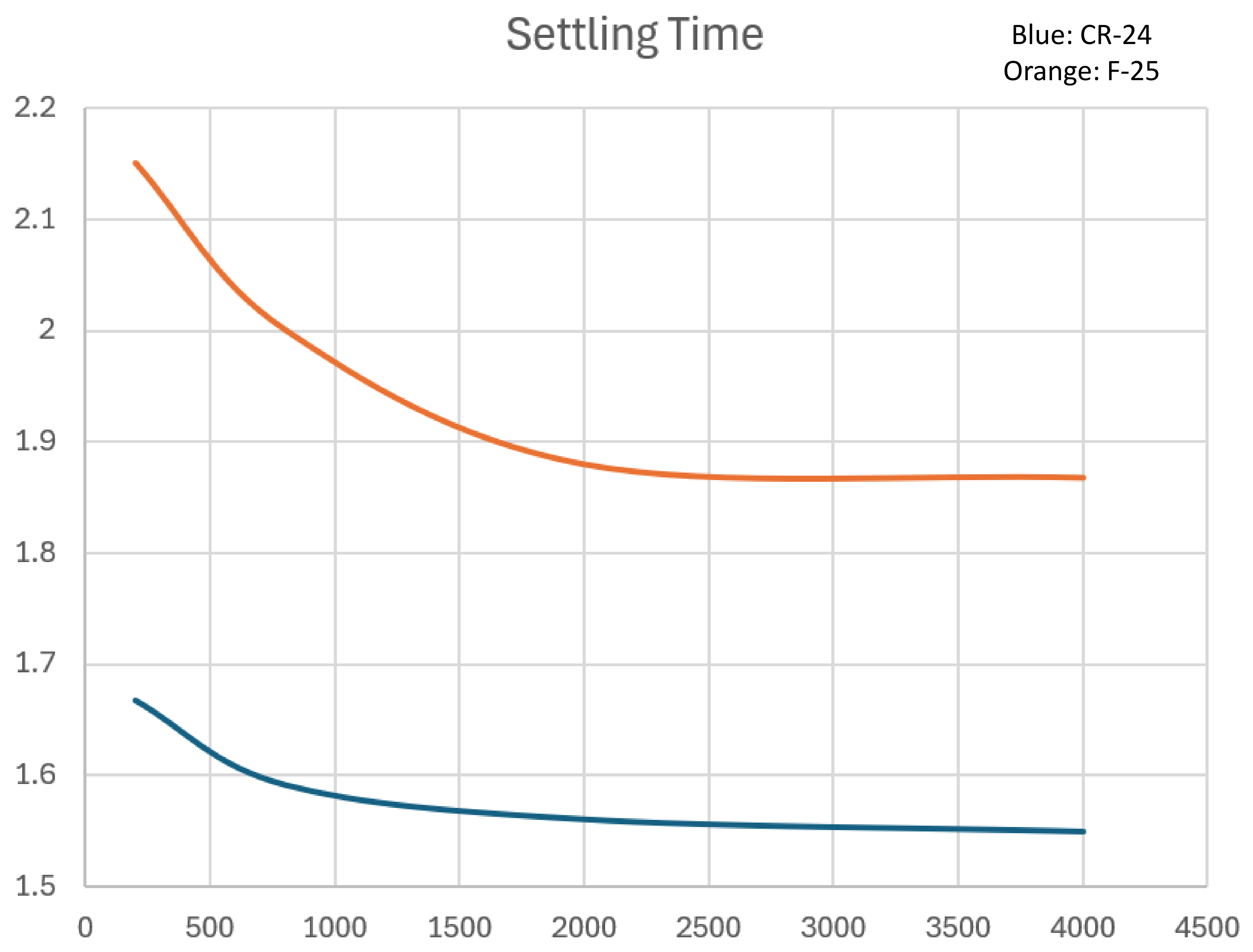
DRAINAGE CHANNEL

Analysis Conditions:
KOOKMIN RACING F-25
Lateral 1.4G





Since the basic suspension of CR-24 is soft, it settles quickly even with low body stiffness.

↓

If the suspension roll stiffness is high, the body stiffness also needs to be high.

Analysis for importance of Body Stiffness in Dynamics

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SUMMARY

STEP STEER:

•If body stiffness is low, it causes errors in the target load transfer.

→ Suspension balance that prevents errors

→ Keeping errors within an acceptable range

DLC, Drainage Channel:

•The difference in movement between rigid and flexible bodies increases when roll stiffness is high.

→ Select body stiffness based on suspension roll stiffness

Numerical sheet application:

•Saves time in the next design phase (No need to run Adams simulation!)

2. Targeting Body Torsional Stiffness

For HIT Formula Project

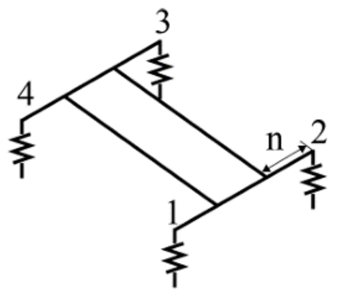
- Select a more precise target body stiffness.
- The process of selecting the target body stiffness will be systematized for use in the development of future vehicles.

For KOOKMIN RACING

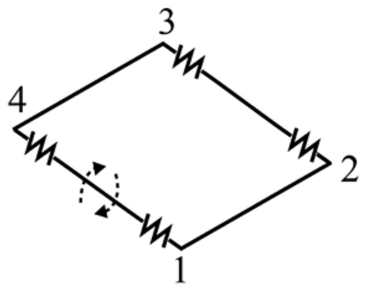
- Select a more accurate target stiffness.
- The goal is to find the target stiffness value that minimizes the impact on vehicle performance while creating the lightest vehicle possible.
- Based on this, we will improve the existing selection method

2. Targeting Body Torsional Stiffness – Last Week

Selecting the target body stiffness through suspension, body spring equivalent models.



(a)



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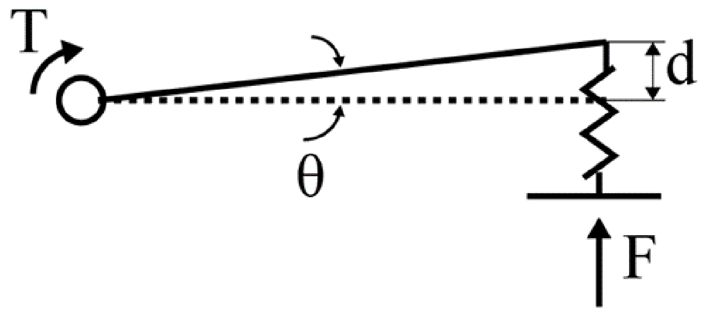


$$k_t = \frac{T}{\theta} = \frac{FLcos\,(\theta)}{tan^{-1}\left(\frac{d}{Lcos(\theta)}\right)}$$

$$Small\ angle : cos\,(\theta) \approx 1 \quad \& \quad tan\,(\theta) = \frac{d}{Lcos\,(\theta)} \approx \theta$$

$$k_t \approx \frac{FL^2}{d} = k_l \cdot L^2$$

$$\frac{1}{K_t} = \frac{1}{k_{t1}} + \frac{1}{k_{t2}} + \frac{1}{k_{t3}} + \frac{1}{k_{t4}} = \sum_{i=1}^{4} \frac{1}{k_{ti}} = \sum_{i=1}^{4} \frac{1}{k_{li} \cdot n_i^2}$$

$$\frac{1}{K_t} = \frac{1}{K_c} + \frac{1}{K_s} + \sum_{i=1}^{4} \frac{1}{k_{li} \cdot n_i^2} \qquad \frac{1}{K_t} = \frac{1}{K_c} + \frac{1}{K_s} + \sum_{i=1}^{4} \frac{1}{k_{si} \cdot (mr)_i^2 \cdot n_i^2}$$

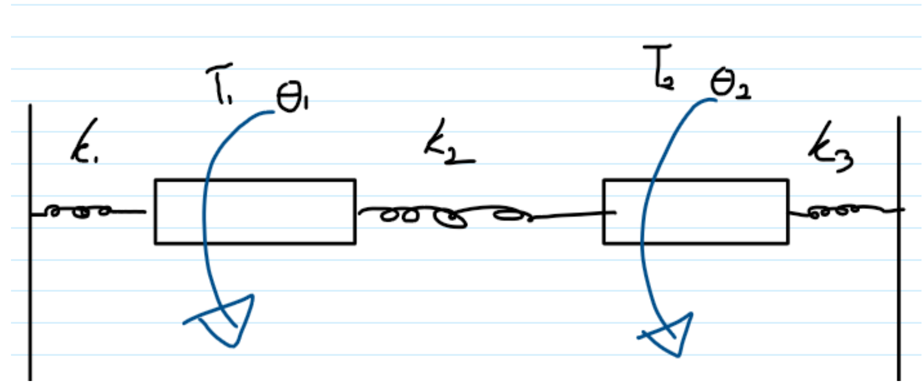
Target: 3,200Nm/deg
Real: 3,100Nm/deg
Sufficient: 2.500Nm/deg

Target: 3,900Nm/deg
Real: 5,350Nm/deg
Sufficient: 3,500Nm/deg

Target: 1,400Nm/deg
Real: No Test Before
Sufficient: 2,000Nm/deg

Numerical Sheet for Simplified Body Stiffness Selection

Body Stiffness By Suspension Roll Stiffness



$$\frac{\frac{1}{K1}+\frac{1}{K3}}{\frac{1}{K1}+\frac{1}{K3}+\frac{1}{K2}} \times 100$$

Series Torsional Spring Including Body Stiffness

Series Torsional Spring Excluding Body Stiffness

Body Stiffness (Nm/deg) / Suspension Contribution (%)									
0	0.00	1500	78.48	3000	87.94	4500	91.63	6000	93.58	7500	94.80
50	10.84	1550	79.03	3050	88.12	4550	91.71	6050	93.63	7550	94.83
100	19.56	1600	79.55	3100	88.29	4600	91.79	6100	93.68	7600	94.87
150	26.72	1650	80.05	3150	88.45	4650	91.87	6150	93.73	7650	94.90
200	32.72	1700	80.52	3200	88.61	4700	91.95	6200	93.78	7700	94.93
250	37.80	1750	80.97	3250	88.77	4750	92.03	6250	93.83	7750	94.96
300	42.17	1800	81.40	3300	88.92	4800	92.11	6300	93.87	7800	94.99
350	45.97	1850	81.81	3350	89.06	4850	92.18	6350	93.92	7850	95.02
400	49.30	1900	82.20	3400	89.21	4900	92.26	6400	93.96	7900	95.05
450	52.25	1950	82.58	3450	89.35	4950	92.33	6450	94.01	7950	95.08
500	54.87	2000	82.94	3500	89.48	5000	92.40	6500	94.05	8000	95.11
550	57.21	2050	83.29	3550	89.62	5050	92.47	6550	94.09	8050	95.14
600	59.33	2100	83.62	3600	89.75	5100	92.54	6600	94.13	8100	95.17
650	61.24	2150	83.94	3650	89.87	5150	92.60	6650	94.17	8150	95.20
700	62.99	2200	84.25	3700	90.00	5200	92.67	6700	94.22	8200	95.22
750	64.58	2250	84.54	3750	90.12	5250	92.73	6750	94.26	8250	95.25
800	66.04	2300	84.83	3800	90.23	5300	92.80	6800	94.30	8300	95.28
850	67.39	2350	85.10	3850	90.35	5350	92.86	6850	94.34	8350	95.31
900	68.63	2400	85.37	3900	90.46	5400	92.92	6900	94.37	8400	95.33
950	69.79	2450	85.62	3950	90.57	5450	92.98	6950	94.41	8450	95.36
1000	70.86	2500	85.87	4000	90.68	5500	93.04	7000	94.45	8500	95.38
1050	71.85	2550	86.11	4050	90.78	5550	93.10	7050	94.49	8550	95.41
1100	72.78	2600	86.34	4100	90.88	5600	93.16	7100	94.52	8600	95.44
1150	73.66	2650	86.56	4150	90.98	5650	93.21	7150	94.56	8650	95.46
1200	74.47	2700	86.78	4200	91.08	5700	93.27	7200	94.60	8700	95.49
1250	75.24	2750	86.99	4250	91.18	5750	93.32	7250	94.63	8750	95.51
1300	75.96	2800	87.19	4300	91.27	5800	93.38	7300	94.67	8800	95.53
1350	76.65	2850	87.39	4350	91.36	5850	93.43	7350	94.70	8850	95.56
1400	77.29	2900	87.58	4400	91.45	5900	93.48	7400	94.73	8900	95.58
1450	77.90	2950	87.76	4450	91.54	5950	93.53	7450	94.77	8950	95.61

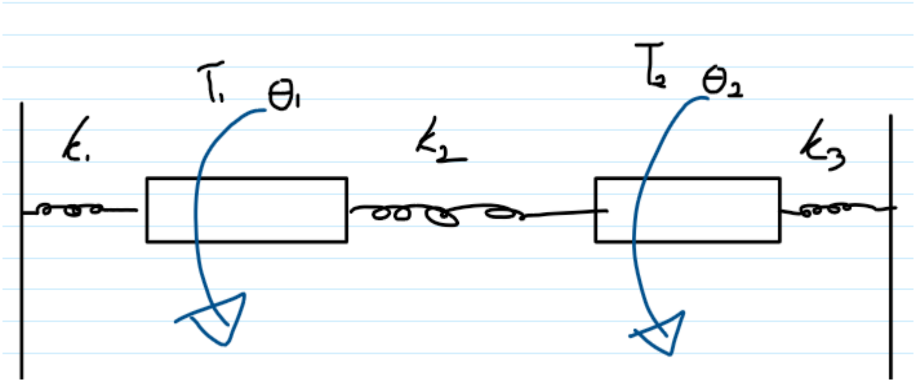
Select body stiffness where the suspension contribution is originally around 90%.

=> Adjust to select body stiffness where the suspension contribution is 88%.

Numerical Sheet for Simplified Body Stiffness Selection

KOOKMIN RACING HFP HIT FORMULA PROJECT FORMULA SAE TEAM

Body Stiffness By Lateral Load Transfer Error



$$\begin{bmatrix} k_1 + k_2 & -k_2 \\ -k_2 & k_2 + k_3 \end{bmatrix} \begin{bmatrix} \theta_1 \\ \theta_2 \end{bmatrix} = \begin{bmatrix} T_1 \\ T_2 \end{bmatrix}$$

Front roll, Rear roll applied

		With BS								With out BS		error rate	
Lat.Acc (G)	Lateral.Acc (m/s^2	delta F	delta R	plus delta	calculated	front in	front out	rear in	rear out	delta F	delta R	Front	Rear
0	0	0	0	0	0	731	731	740	740	0	0	0	0
0.1	0.9806	41.627174	45.3752752	174.004898	81.8696681	689	773	694	785	41.7231119	45.2768557	0.22994048	-0.217372615
0.2	1.9612	83.254347	90.7505504	348.009795	163.739336	648	814	649	831	83.4462239	90.5537114	0.22994048	-0.217372615
0.3	2.9418	124.88152	136.125826	522.014693	245.609004	606	856	604	876	125.169336	135.830567	0.22994048	-0.217372615
0.4	3.9224	166.50869	181.501101	696.01959	327.478672	565	898	558	921	166.892448	181.107423	0.22994048	-0.217372615
0.5	4.903	208.13587	226.876376	870.024488	409.34834	523	939	513	967	208.61556	226.384278	0.22994048	-0.217372615
0.6	5.8836	249.76304	272.251651	1044.02939	491.218009	481	981	468	1012	250.338672	271.661134	0.22994048	-0.217372615
0.7	6.8642	291.39022	317.626926	1218.03428	573.087677	440	1022	422	1057	292.061784	316.93799	0.22994048	-0.217372615
0.8	7.8448	333.01739	363.002201	1392.03918	654.957345	398	1064	377	1103	333.784895	362.214846	0.22994048	-0.217372615
0.9	8.8254	374.64456	408.377477	1566.04408	736.827013	356	1106	331	1148	375.508007	407.491701	0.22994048	-0.217372615
1	9.806	416.27174	453.752752	1740.04898	818.696681	315	1147	286	1194	417.231119	452.768557	0.22994048	-0.217372615
1.1	10.7866	457.89891	499.128027	1914.05387	900.566349	273	1189	241	1239	458.954231	498.045413	0.22994048	-0.217372615
1.2	11.7672	499.52608	544.503302	2088.05877	982.436017	232	1231	195	1284	500.677343	543.322268	0.22994048	-0.217372615
1.3	12.7478	541.15326	589.878577	2262.06367	1064.30569	190	1272	150	1330	542.400455	588.599124	0.22994048	-0.217372615
1.4	13.7284	582.78043	635.253852	2436.06857	1146.17535	148	1314	105	1375	584.123567	633.87598	0.22994048	-0.217372615
1.5	14.709	624.4076	680.629128	2610.07346	1228.04502	107	1355	59	1420	625.846679	679.152835	0.22994048	-0.217372615
1.6	15.6896	666.03478	726.004403	2784.07836	1309.91469	65	1397	14	1466	667.569791	724.429691	0.22994048	-0.217372615
1.7	16.6702	707.66195	771.379678	2958.08326	1391.78436	23	1439	-32	1511	709.292903	769.706547	0.22994048	-0.217372615
1.8	17.6508	749.28912	816.754953	3132.08816	1473.65403	-18	1480	-77	1557	751.016015	814.983402	0.22994048	-0.217372615
1.9	18.6314	790.9163	862.130228	3306.09305	1555.52369	-60	1522	-122	1602	792.739127	860.260258	0.22994048	-0.217372615
2	19.612	832.54347	907.505504	3480.09795	1637.39336	-102	1564	-168	1647	834.462239	905.537114	0.22994048	-0.217372615
2.1	20.5926	874.17065	952.880779	3654.10285	1719.26303	-143	1605	-213	1693	876.185351	950.813969	0.22994048	-0.217372615
2.2	21.5732	915.79782	998.256054	3828.10775	1801.1327	-185	1647	-258	1738	917.908463	996.090825	0.22994048	-0.217372615
2.3	22.5538	957.42499	1043.63133	4002.11264	1883.00237	-226	1688	-304	1783	959.631574	1041.36768	0.22994048	-0.217372615
2.4	23.5344	999.05217	1089.0066	4176.11754	1964.87203	-268	1730	-349	1829	1001.35469	1086.64454	0.22994048	-0.217372615
2.5	24.515	1040.6793	1134.38188	4350.12244	2046.7417	-310	1772	-395	1874	1043.0778	1131.92139	0.22994048	-0.217372615

Pass if the error is within about 0.5%.

If high body stiffness is not possible, choose a combination of roll center and roll stiffness where the error rate does not change even if body stiffness changes.

3. Body Torsional Stiffness Simulation

ALTAIR

For HIT Formula Project

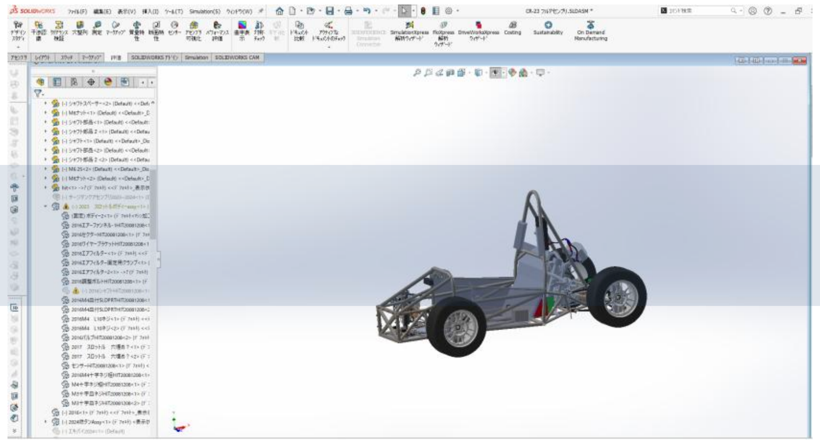
- The HIT vehicle stiffness is evaluated by applying more advanced analysis conditions compared to the previous torsional analysis.
- Simulations are conducted using ALTAIR's simulation tools, a key partner of Formula Student, and the results are compared.
- This activity provides experience in performing both the new analysis condition simulations and the actual measurement process simultaneously

For KOOKMIN RACING

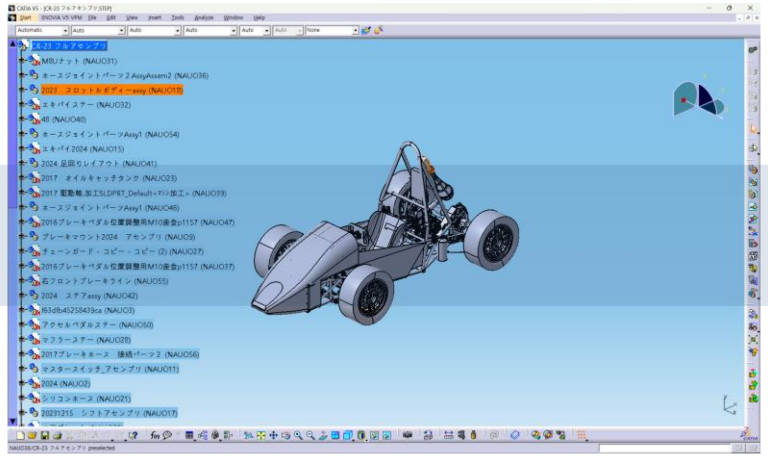
- By using both SolidWorks and CATIA, two leading 3D CAD tools, the advantages of each are maximized.
- Bending stiffness, which is highly valued at HIT, is considered, and analysis conditions are studied based on assumed real driving scenarios.

3. Body Torsional Stiffness Simulation – Last Week

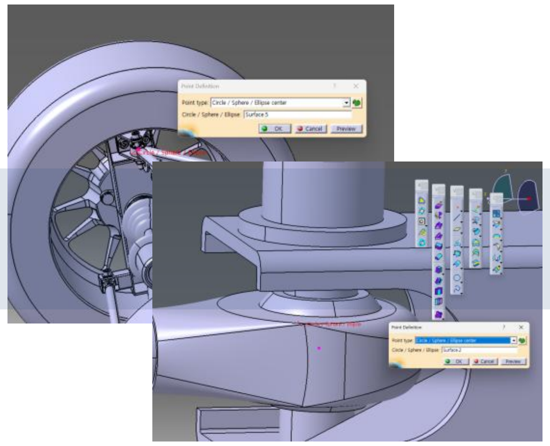
ALTAIR Hyperworks Modeling



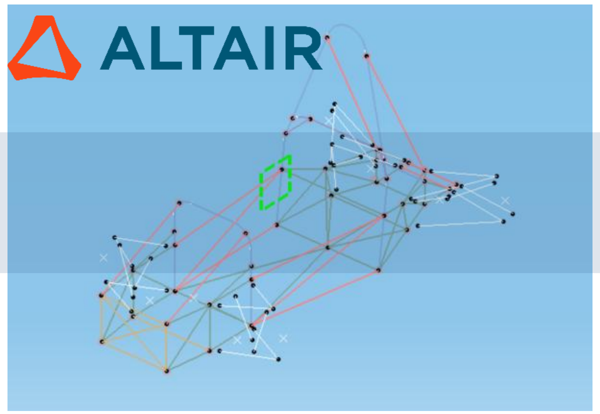
Solidworks 3D Modeling



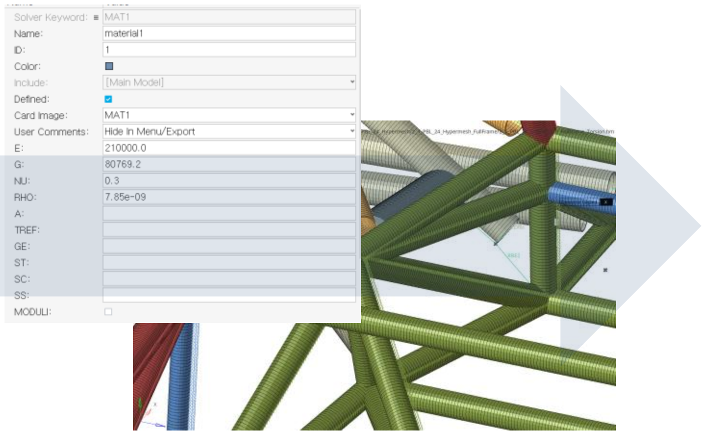
Redrawing at CATIA V5



Point Extraction



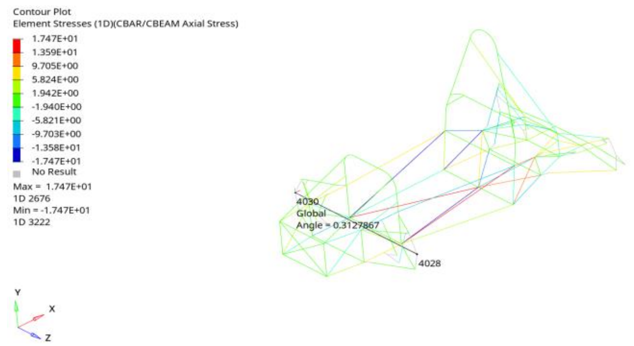
Sim Model Drawing



Inserting Material, Spec

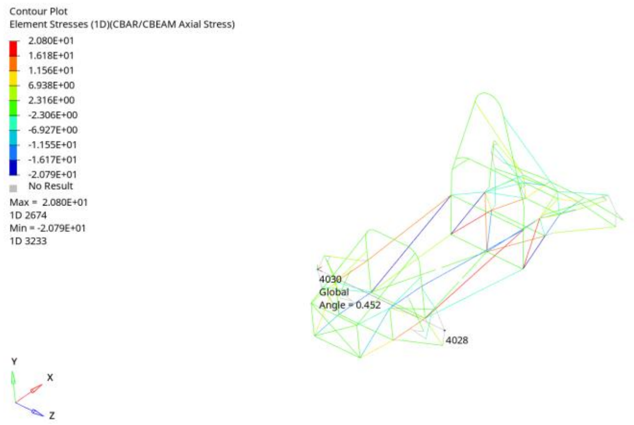
Simulation Result

1. Torsional Stiffness



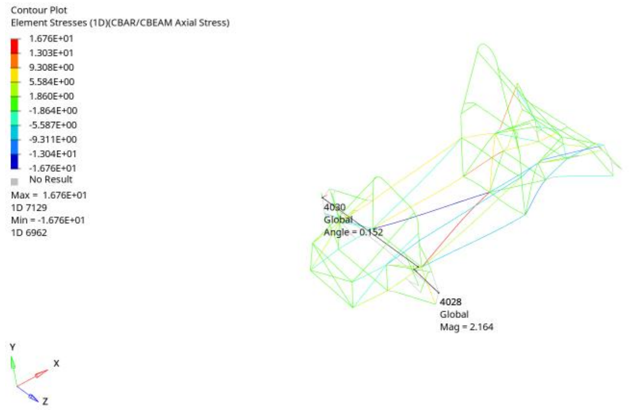
Max Torsional Stiffness
:1000Nx0.540m/0.313deg
= 1,725Nm/deg

30.78% Low Stiffness



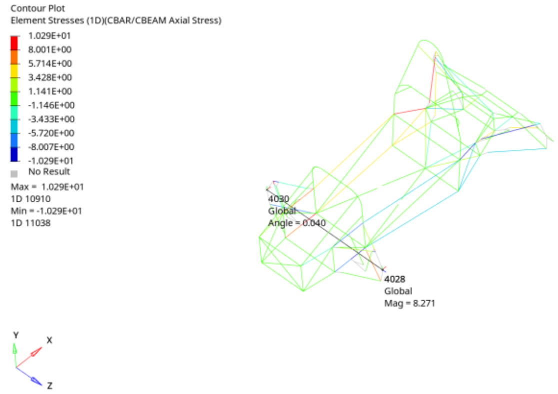
Max Torsional Stiffness
:1000Nx0.540m/0.452deg
= 1,194Nm/deg

2. Bending Stiffness



Relative Angle: 0.040 deg
Maximum Displacement: 2.164 mm

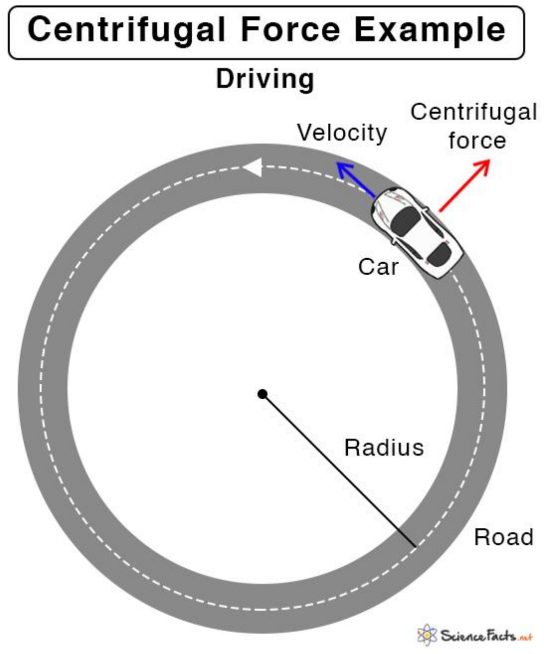
73.68% More Torsion
73.84% More Displacement



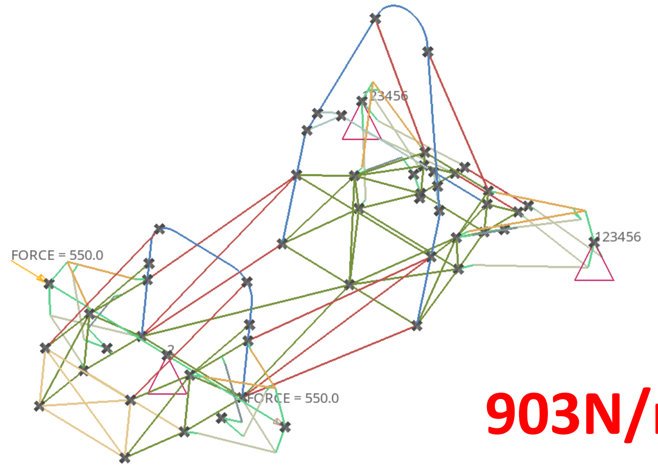
Relative Angle: 0.152 deg
Maximum Displacement: 8.271 mm

3. Body Torsional Stiffness Simulation – This Week

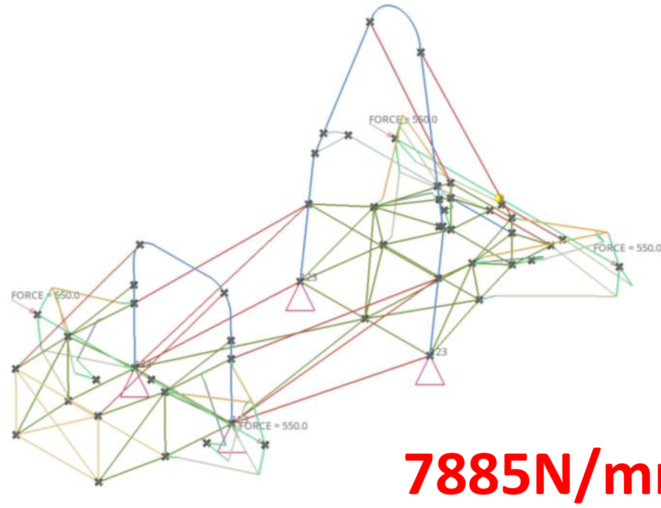
Lateral Bending caused by centrifugal force



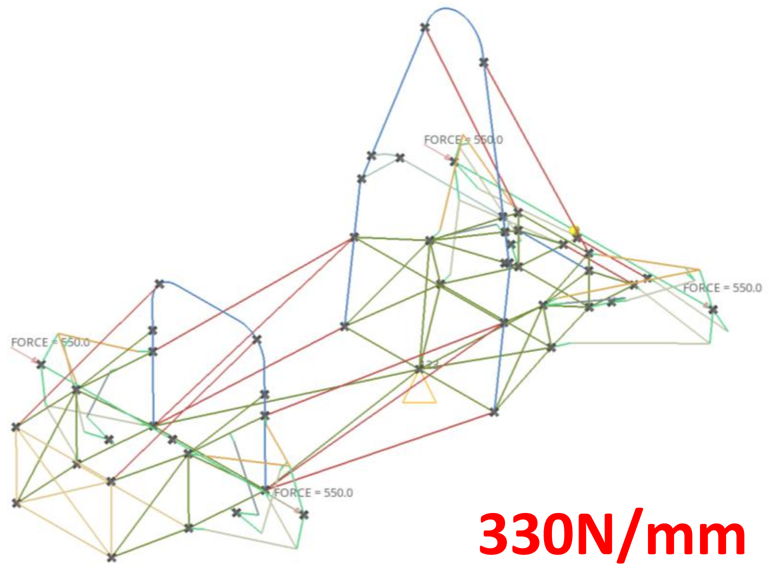
Trying various boundary conditions to find the best representative model



903N/mm

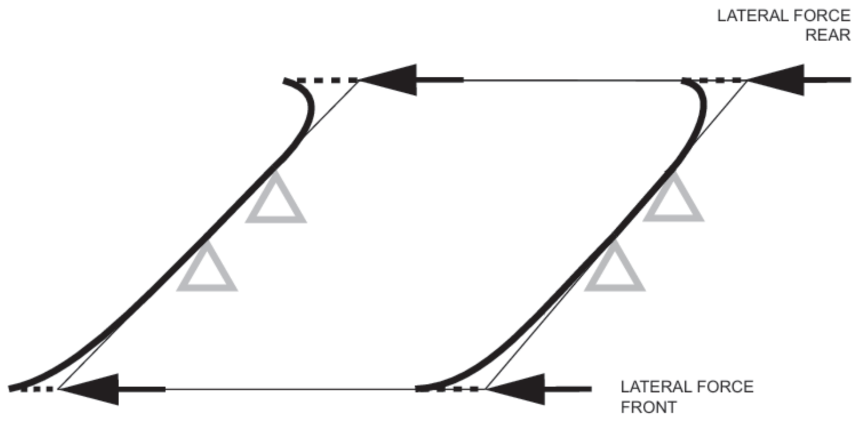


7885N/mm



330N/mm

Global Lateral Stifness is hard to be considerd



3. Body Torsional Stiffness Simulation – This Week

Vertical Bending

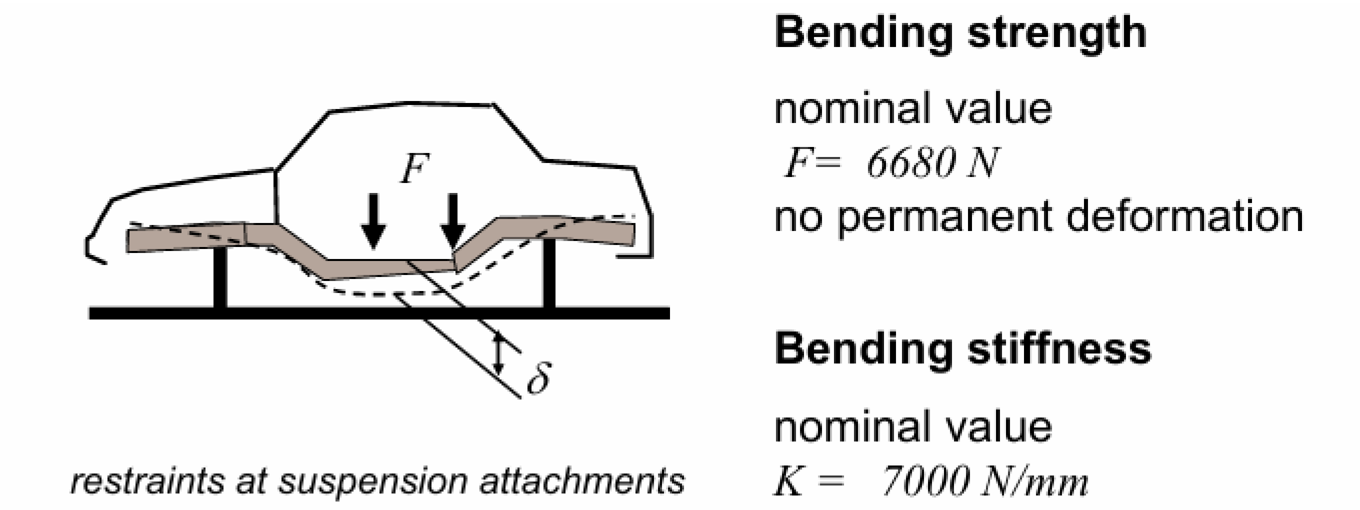
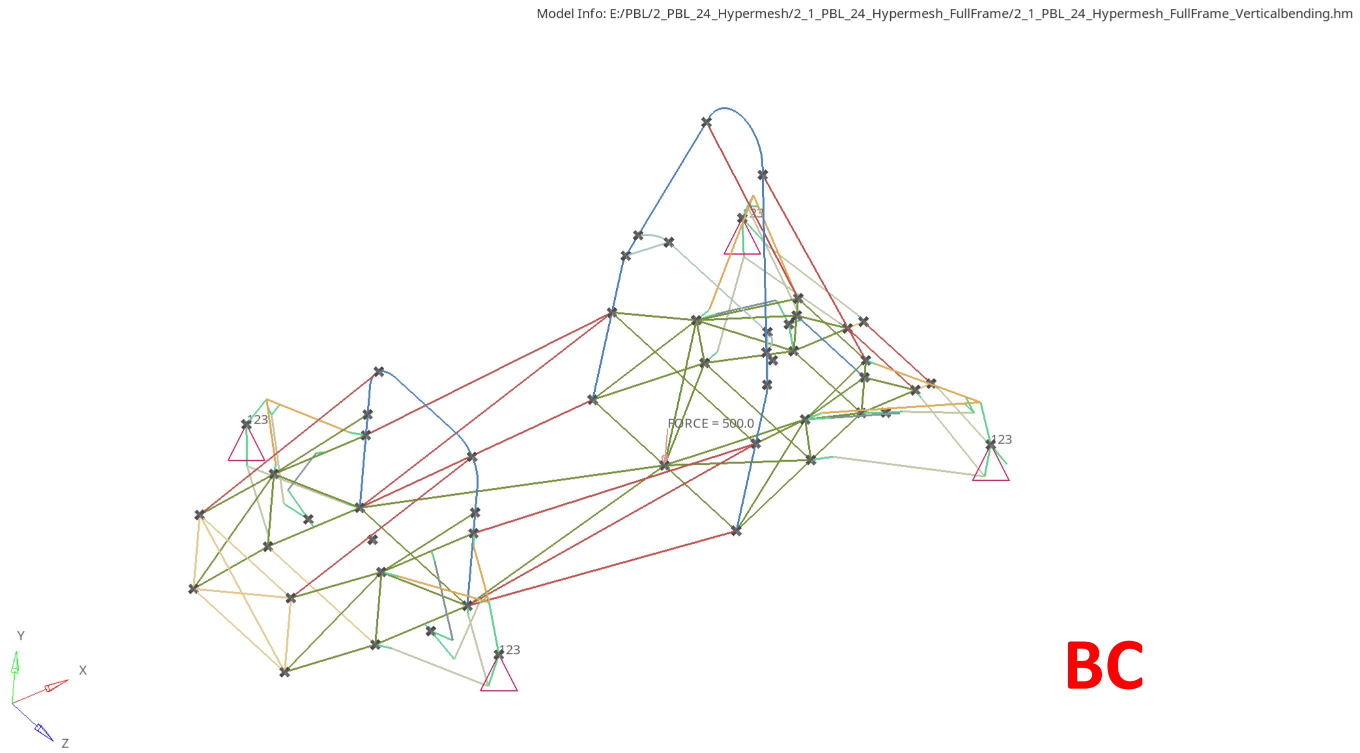
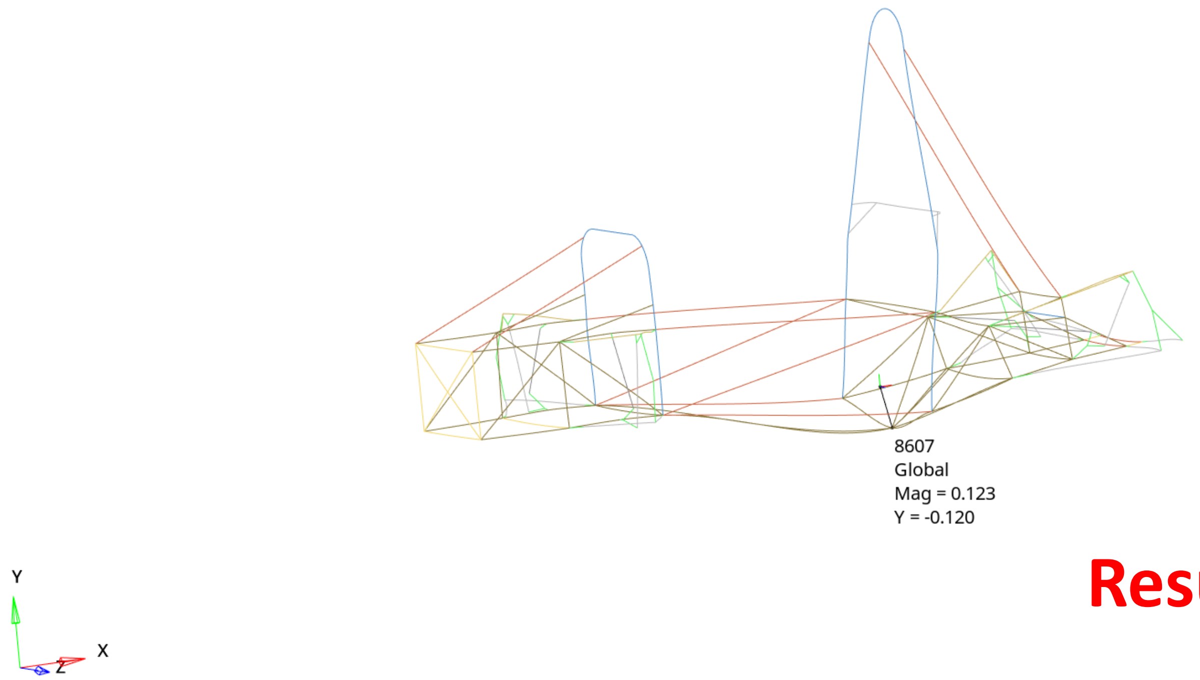


Figure 4.14 Typical bending requirements: Midsize vehicle.



BC

Normally high torsional stiffness also shows much higher vertical bending stiffness



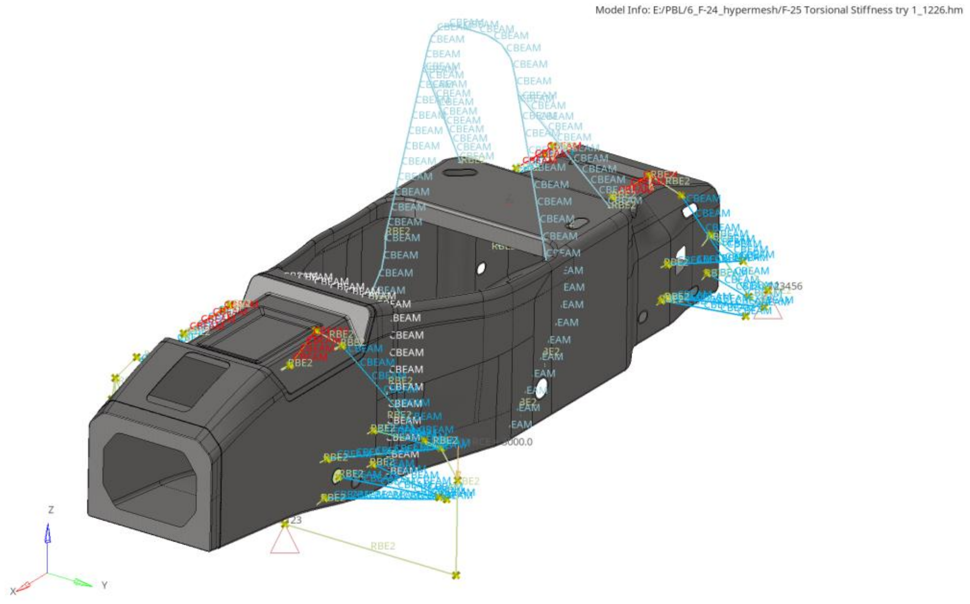
Result

3. Body Torsional Stiffness Simulation – This Week

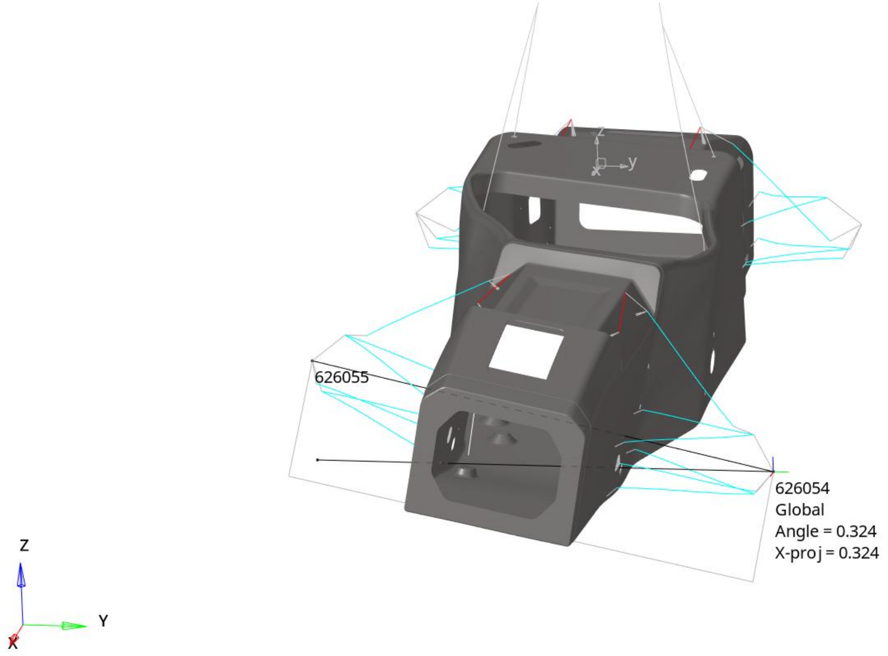
KOOKMIN RACING
HFP HIT FORMULA PROJECT
FORMULA SAE TEAM

Torsional stiffenss of F-25

CAD

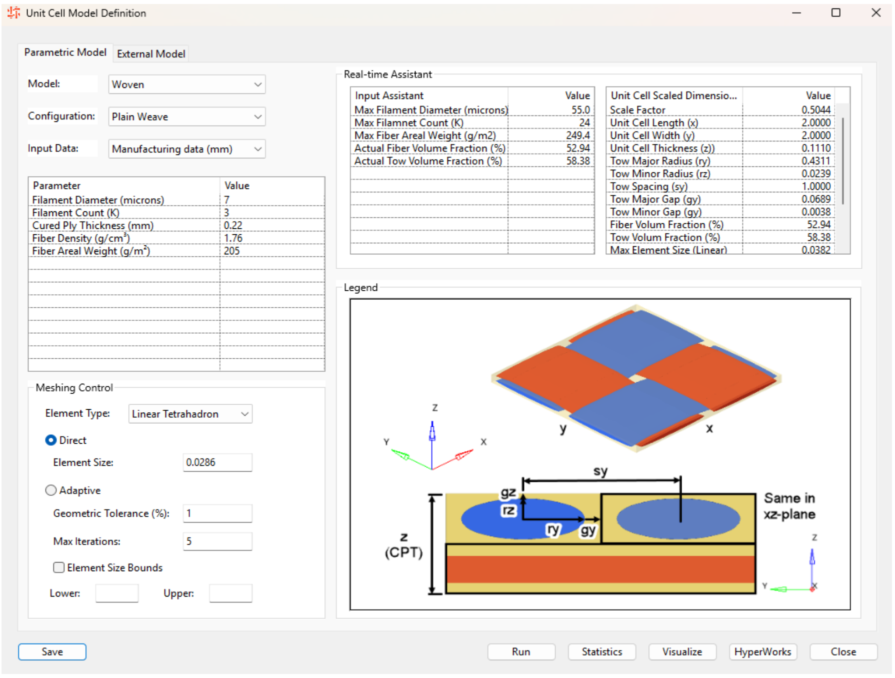


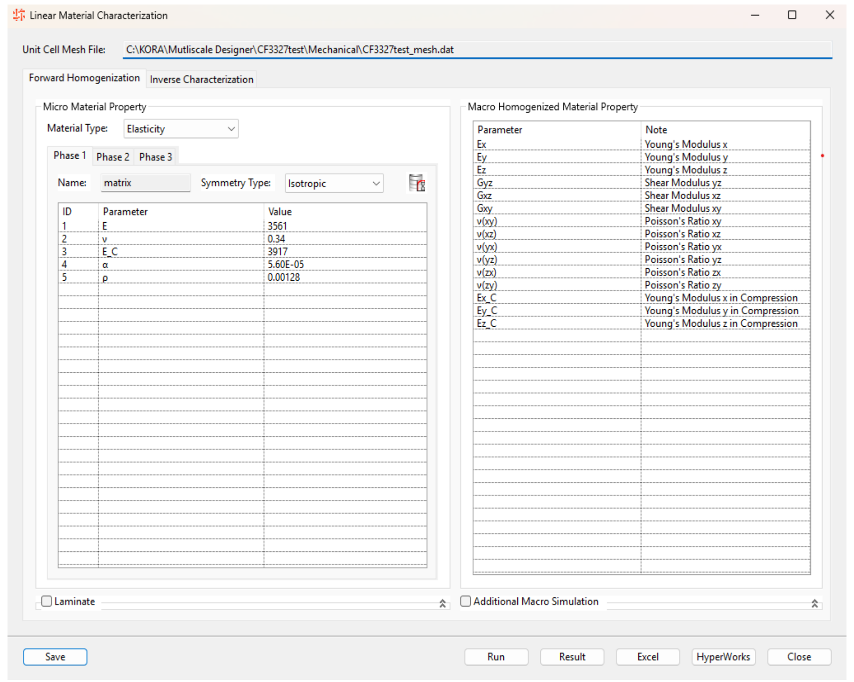
FEM Model



FEM Model

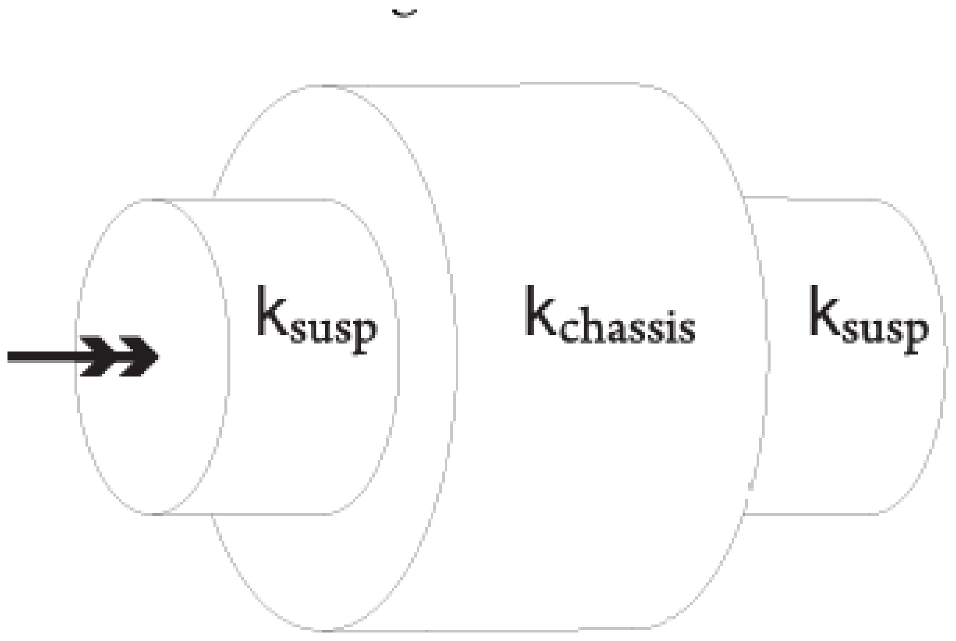
Due to some material property was missing from manufacturer, I designed my own property for biaxial CFRP by multiscaiing method



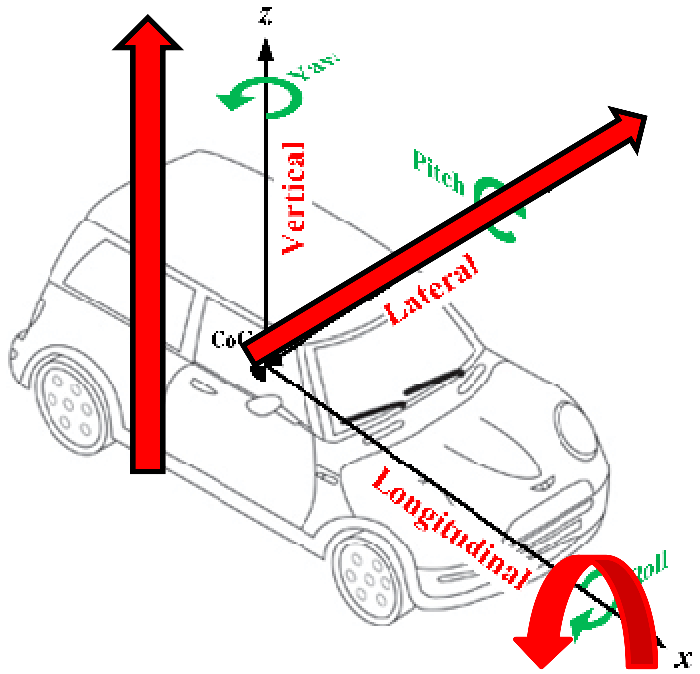


3. Body Torsional Stiffness Simulation – This Week

Body as spring



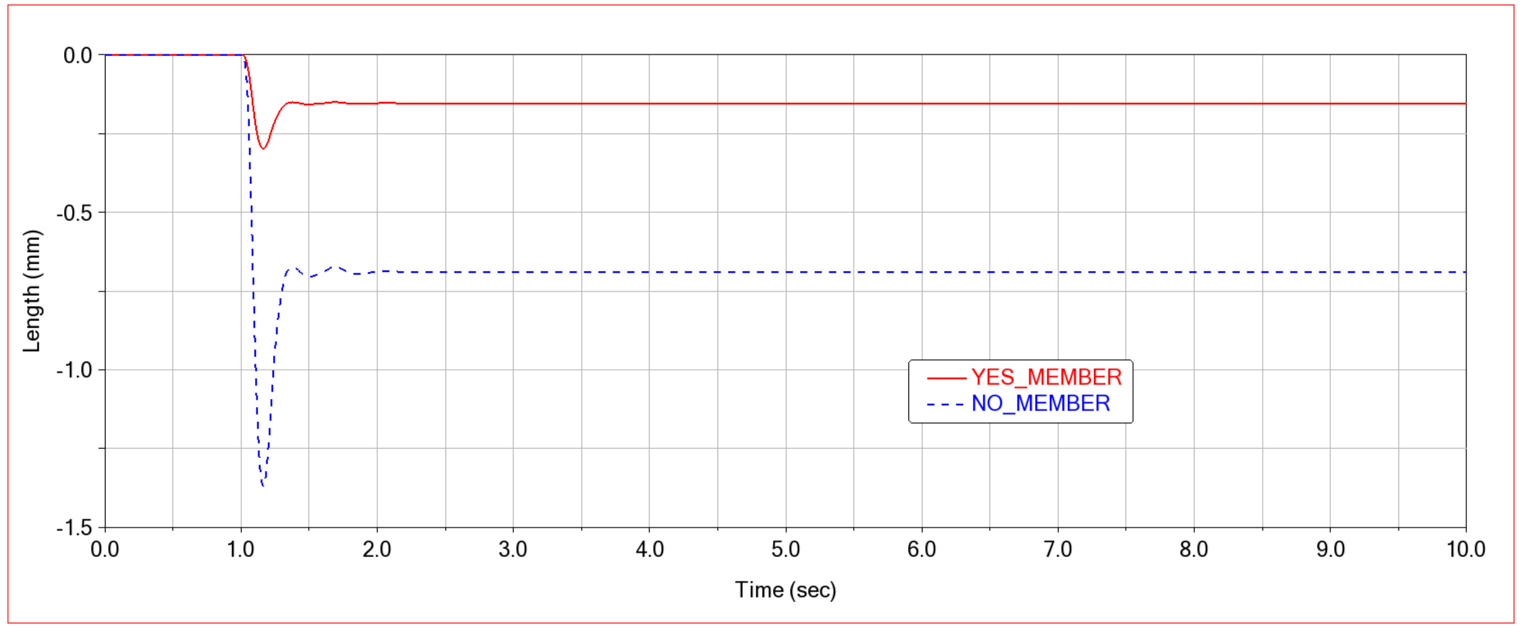
Organized data from FEM

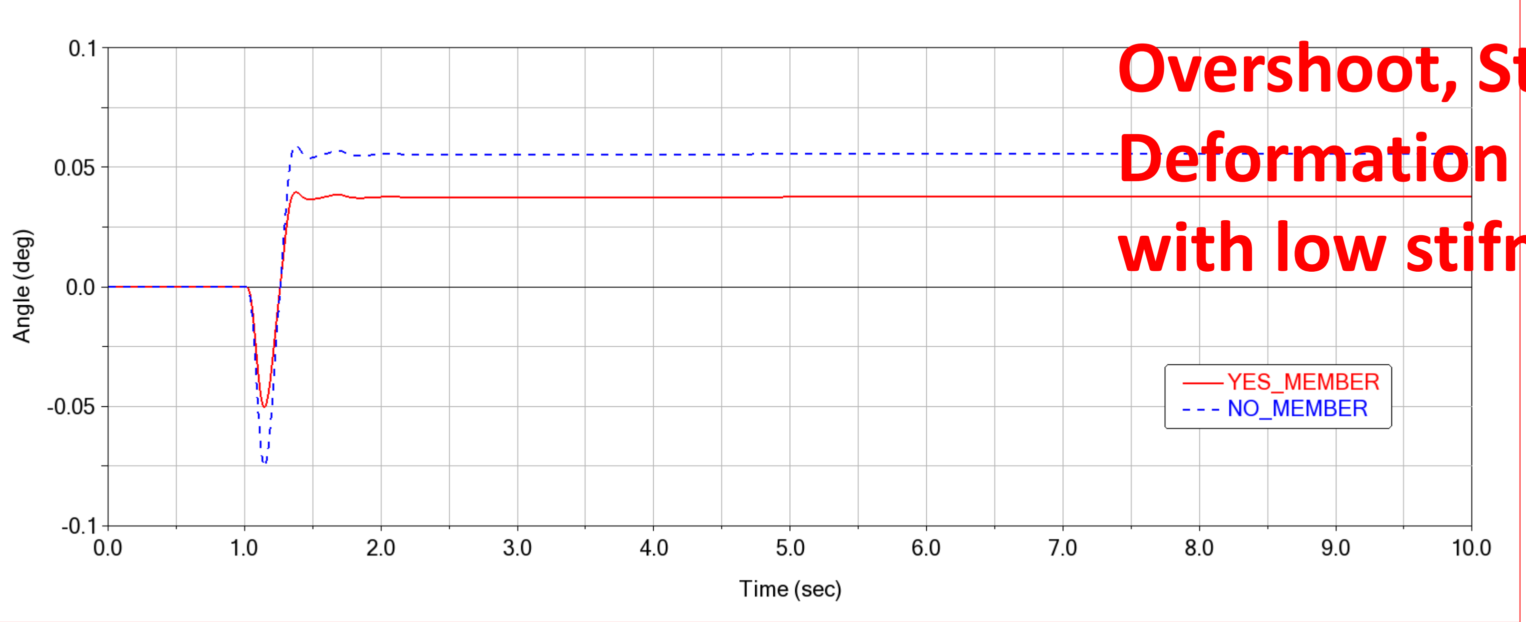


	FullFrame	CutFrame
Torsion	1843Nmm/deg	1200Nmm/deg
Lateral Case1	903N/mm	202N/mm
Lateral Case2	7885N/mm	7829N/mm
Lateral Case3	330N/mm	167N/mm
Vertical	4166N/mm	2293N/mm

Lateral, Vertical, Roll was considered

Observed in ADAMS Flexible body model(Vehicle dynamics analysis)





Overshoot, Steady-State Deformation can be 10x lager with low stifness!

4. Body Torsional Stiffness Test

For HIT Formula Project

- An evaluation can be conducted through actual body stiffness measurements to assess the reliability of the analysis.
- This provides an opportunity to introduce the test within Japan.
- Through this test, the validity of the body design can be verified, enhancing the completeness of the design.

For KOOKMIN RACING

- Through this PBL, the first torsional stiffness measurement of the KOOKMIN RACING F-25 will be conducted under the same conditions as the analysis.
- Later, an additional test will be performed with assembled components expected to affect chassis torsion to compare the results.
- This approach provides an opportunity to expand the body stiffness design scope to include component packaging in future vehicle designs.

4. Body Torsional Stiffness Test – Last Week

KOOKMIN RACING
HFP HIT FORMULA PROJECT
FORMULA SAE TEAM

Introduce of Body Torsional Stiffness Test

Purpose of Actual Test:

- It corresponds to the most basic evaluation among the experiments that can be conducted to observe body stiffness.
- By performing measurements that closely match the simulation conditions, the reliability of the analysis can be assessed

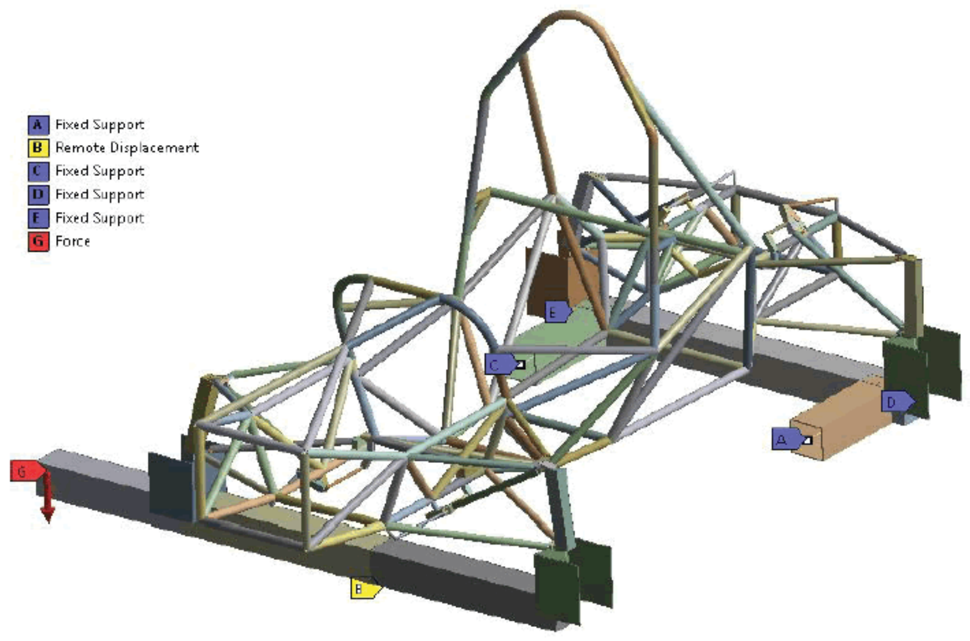
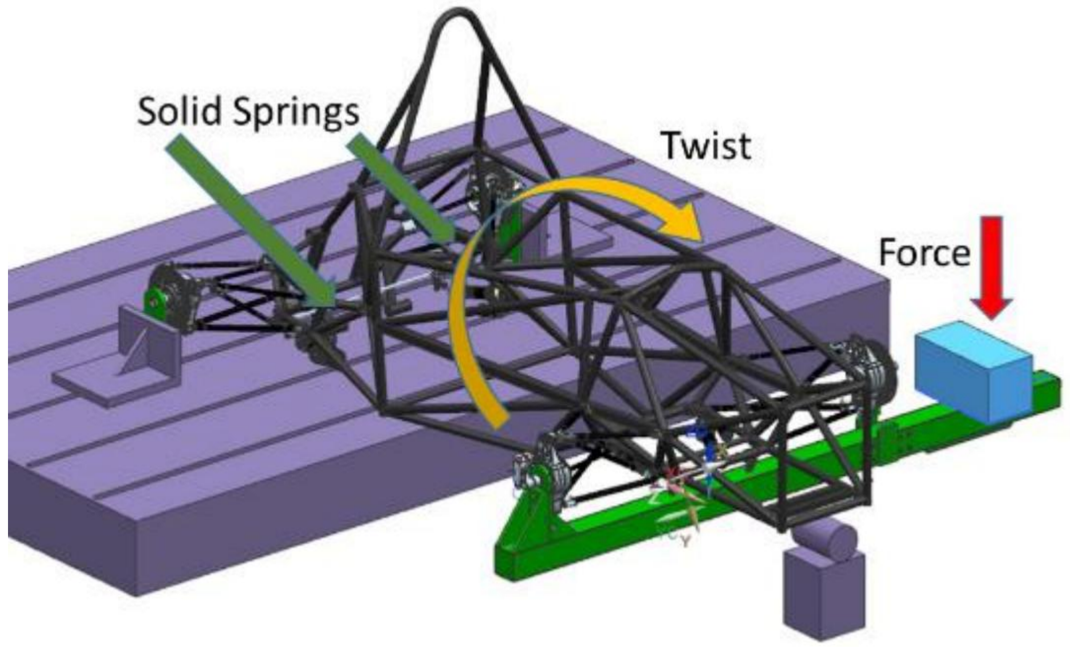
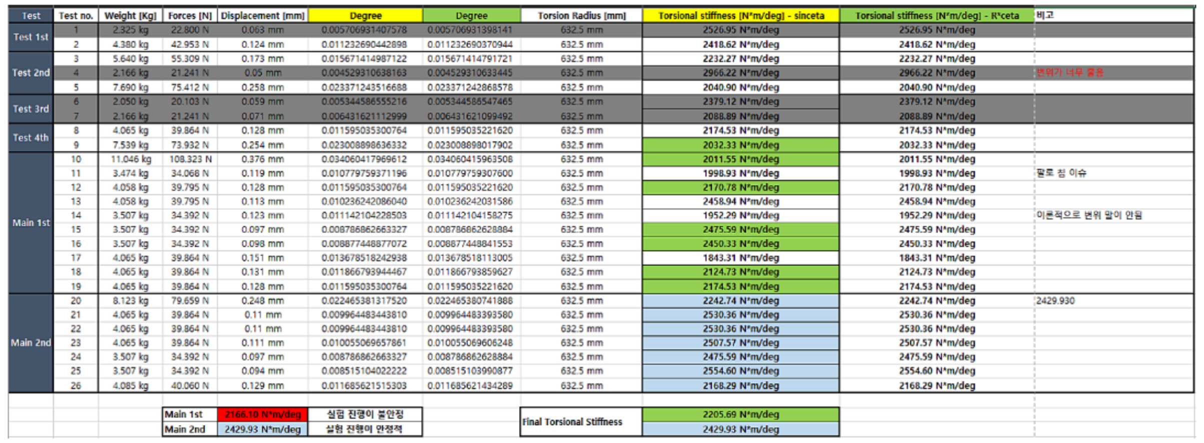


Figure 9: Boundary conditions.

Step 1: FEM



Step 2: Measurement



Test	Test no.	Weight [Kg]	Forces [N]	Displacement [mm]	Degree	Degree	Torsion Radius [mm]	Torsional stiffness [N*m/deg] - sinceta	Torsional stiffness [N*m/deg] - R*ceta	비고
Test 1st	1	2.325 kg	22.800 N	0.063 mm	0.005706931407578	0.005706931398141	632.5 mm	2526.95 N*m/deg	2526.95 N*m/deg	
	2	4.380 kg	42.953 N	0.124 mm	0.011232690442898	0.011232690370944	632.5 mm	2418.62 N*m/deg	2418.62 N*m/deg	
Test 2nd	3	5.640 kg	55.309 N	0.173 mm	0.015671414987122	0.015671414791721	632.5 mm	2232.27 N*m/deg	2232.27 N*m/deg	
	4	2.166 kg	21.241 N	0.05 mm	0.004529310638163	0.004529310633445	632.5 mm	2966.22 N*m/deg	2966.22 N*m/deg	변위가 너무 좋음
	5	7.690 kg	75.412 N	0.258 mm	0.023371243516688	0.023371242868578	632.5 mm	2040.90 N*m/deg	2040.90 N*m/deg	
Test 3rd	6	2.050 kg	20.103 N	0.059 mm	0.005344586555216	0.005344586547465	632.5 mm	2379.12 N*m/deg	2379.12 N*m/deg	
	7	2.166 kg	21.241 N	0.071 mm	0.006431621112999	0.006431621099492	632.5 mm	2088.89 N*m/deg	2088.89 N*m/deg	
Test 4th	8	4.065 kg	39.864 N	0.128 mm	0.011595035300764	0.011595035221620	632.5 mm	2174.53 N*m/deg	2174.53 N*m/deg	
	9	7.539 kg	73.932 N	0.254 mm	0.023008898636332	0.023008898017902	632.5 mm	2032.33 N*m/deg	2032.33 N*m/deg	
Main 1st	10	11.046 kg	108.323 N	0.376 mm	0.034060417969612	0.034060415963508	632.5 mm	2011.55 N*m/deg	2011.55 N*m/deg	
	11	3.474 kg	34.068 N	0.119 mm	0.010779759371196	0.010779759307600	632.5 mm	1998.93 N*m/deg	1998.93 N*m/deg	팔로 침 이슈
	12	4.058 kg	39.795 N	0.128 mm	0.011595035300764	0.011595035221620	632.5 mm	2170.78 N*m/deg	2170.78 N*m/deg	
	13	4.058 kg	39.795 N	0.113 mm	0.010236242086040	0.010236242031586	632.5 mm	2458.94 N*m/deg	2458.94 N*m/deg	
	14	3.507 kg	34.392 N	0.123 mm	0.011142104228503	0.011142104158275	632.5 mm	1952.29 N*m/deg	1952.29 N*m/deg	이론적으로 변위 말이 안됨
	15	3.507 kg	34.392 N	0.097 mm	0.008786862663327	0.008786862628884	632.5 mm	2475.59 N*m/deg	2475.59 N*m/deg	
	16	3.507 kg	34.392 N	0.098 mm	0.008877448877072	0.008877448841553	632.5 mm	2450.33 N*m/deg	2450.33 N*m/deg	
	17	4.065 kg	39.864 N	0.151 mm	0.013678518242938	0.013678518113005	632.5 mm	1843.31 N*m/deg	1843.31 N*m/deg	
	18	4.065 kg	39.864 N	0.131 mm	0.011866793944467	0.011866793859627	632.5 mm	2124.73 N*m/deg	2124.73 N*m/deg	
	19	4.065 kg	39.864 N	0.128 mm	0.011595035300764	0.011595035221620	632.5 mm	2174.53 N*m/deg	2174.53 N*m/deg	
Main 2nd	20	8.123 kg	79.659 N	0.248 mm	0.022465381317520	0.022465380741888	632.5 mm	2242.74 N*m/deg	2242.74 N*m/deg	2429.930
	21	4.065 kg	39.864 N	0.11 mm	0.009964483443810	0.009964483393580	632.5 mm	2530.36 N*m/deg	2530.36 N*m/deg	
	22	4.065 kg	39.864 N	0.11 mm	0.009964483443810	0.009964483393580	632.5 mm	2530.36 N*m/deg	2530.36 N*m/deg	
	23	4.065 kg	39.864 N	0.111 mm	0.010055069657861	0.010055069606248	632.5 mm	2507.57 N*m/deg	2507.57 N*m/deg	
	24	3.507 kg	34.392 N	0.097 mm	0.008786862663327	0.008786862628884	632.5 mm	2475.59 N*m/deg	2475.59 N*m/deg	
	25	3.507 kg	34.392 N	0.094 mm	0.008515104022222	0.008515103990877	632.5 mm	2554.60 N*m/deg	2554.60 N*m/deg	
	26	4.085 kg	40.060 N	0.129 mm	0.011685621515303	0.011685621434289	632.5 mm	2168.29 N*m/deg	2168.29 N*m/deg	

Main 1st	2166.10 N*m/deg	실험 진행이 불안정
Main 2nd	2429.93 N*m/deg	실험 진행이 안정적

Final Torsional Stiffness	2205.69 N*m/deg
	2429.93 N*m/deg

Step 3: Analysis

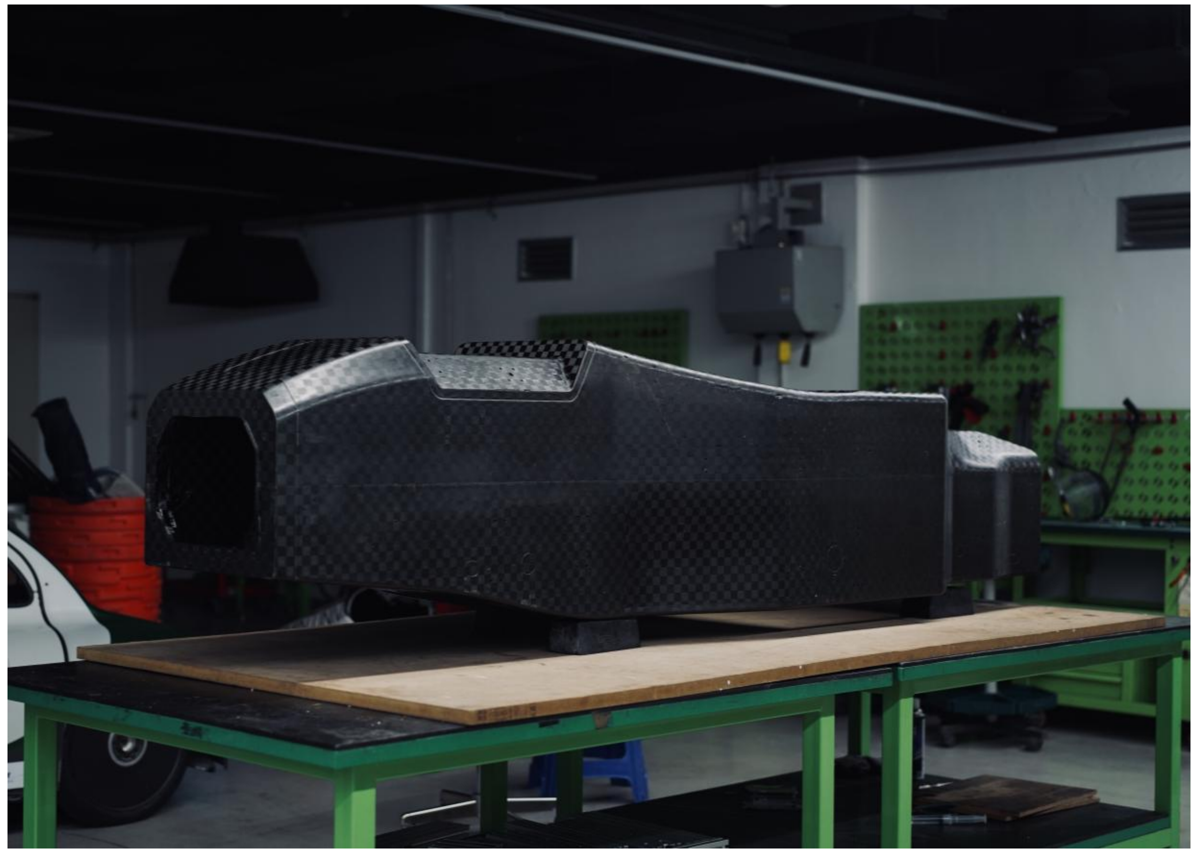
Advantages of the test:

- Easy measurement method
- Relatively low jig manufacturing cost
- Small discrepancy between analysis conditions and actual conditions

4. Body Torsional Stiffness Test – This Week

KOOKMIN RACING HFP HIT FORMULA PROJECT FORMULA SAE TEAM

Before the Test



1. Completed Monocoque

2. Secondary Process

3. Assembling Some Parts

1. ***Completed Monocoque***

Prepare the CFRP monocoque for simulation.

2. ***Secondary Process***

Perform post-processing identical to the simulation modeling (additional hole creation, surface finishing).

3. ***Assembling Some Parts***

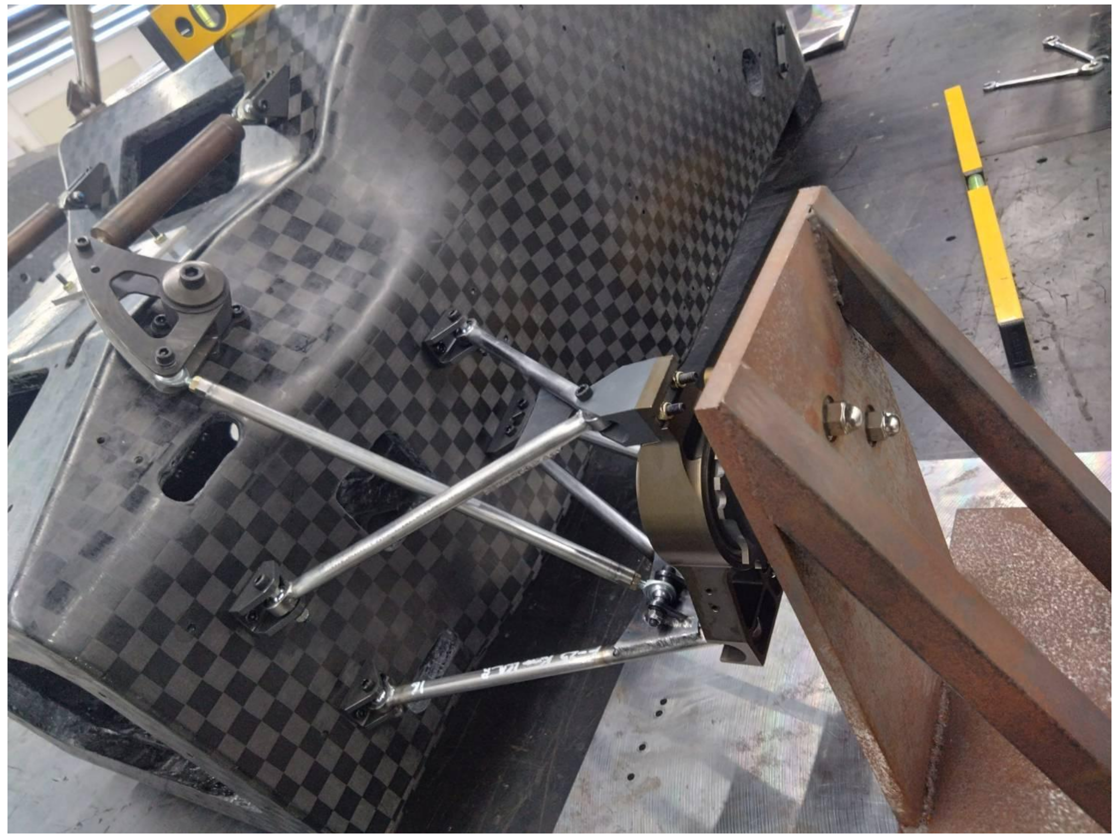
Prepare several individual parts to implement the geometry reflected in the simulation model.

4. Body Torsional Stiffness Test – This Week

KOOKMIN RACING HFP HIT FORMULA PROJECT FORMULA SAE TEAM

Test Setup

1. Assembling Test Zig



2. Detailed Edit

3. Setting the Test

1. Assembling Test Zig

Install the torsional stiffness test jig and solid shock absorbers (to eliminate the effect of suspension torsion)

2. Detailed Edit

Minimize the clearance between the jig and the body, allowing only the body's torsion to be measured

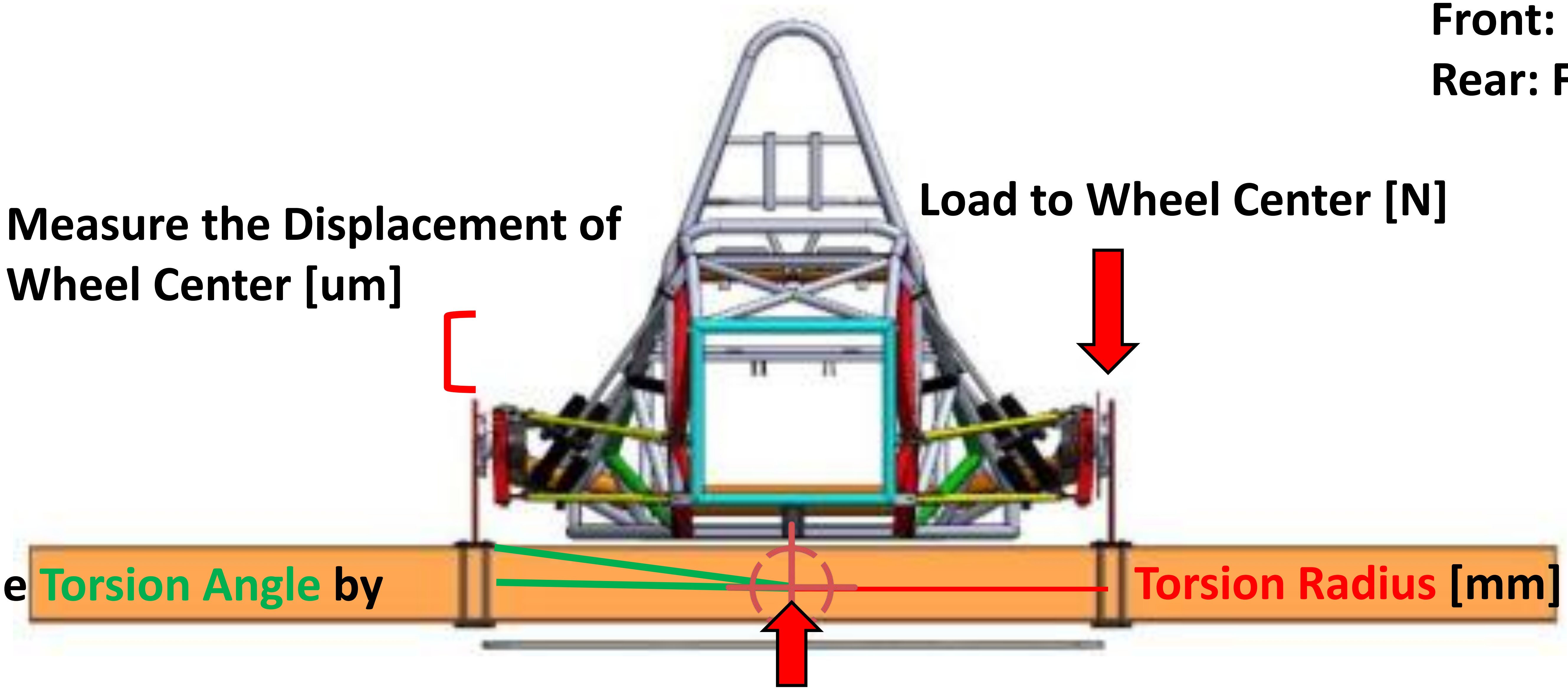
3. Setting the Test

Prepare the measuring equipment and weights in earnest.

4. Body Torsional Stiffness Test – This Week

Test

Front: X-Axis Rotating
Rear: Fixed Wheel Center



Calculate the Torsion Angle by

1. **AcrsinØ**
2. **RØ**

Torsional Stiffness = Load (N) * Torsion Radius [mm] / Torsion Angle [deg]

Important!

1. Minimize the play of the model before testing.
2. Conduct multiple tests to identify trends.
3. Avoid applying excessive loads, as the test jig may experience torsion.

4. Body Torsional Stiffness Test – This Week

KOOKMIN RACING
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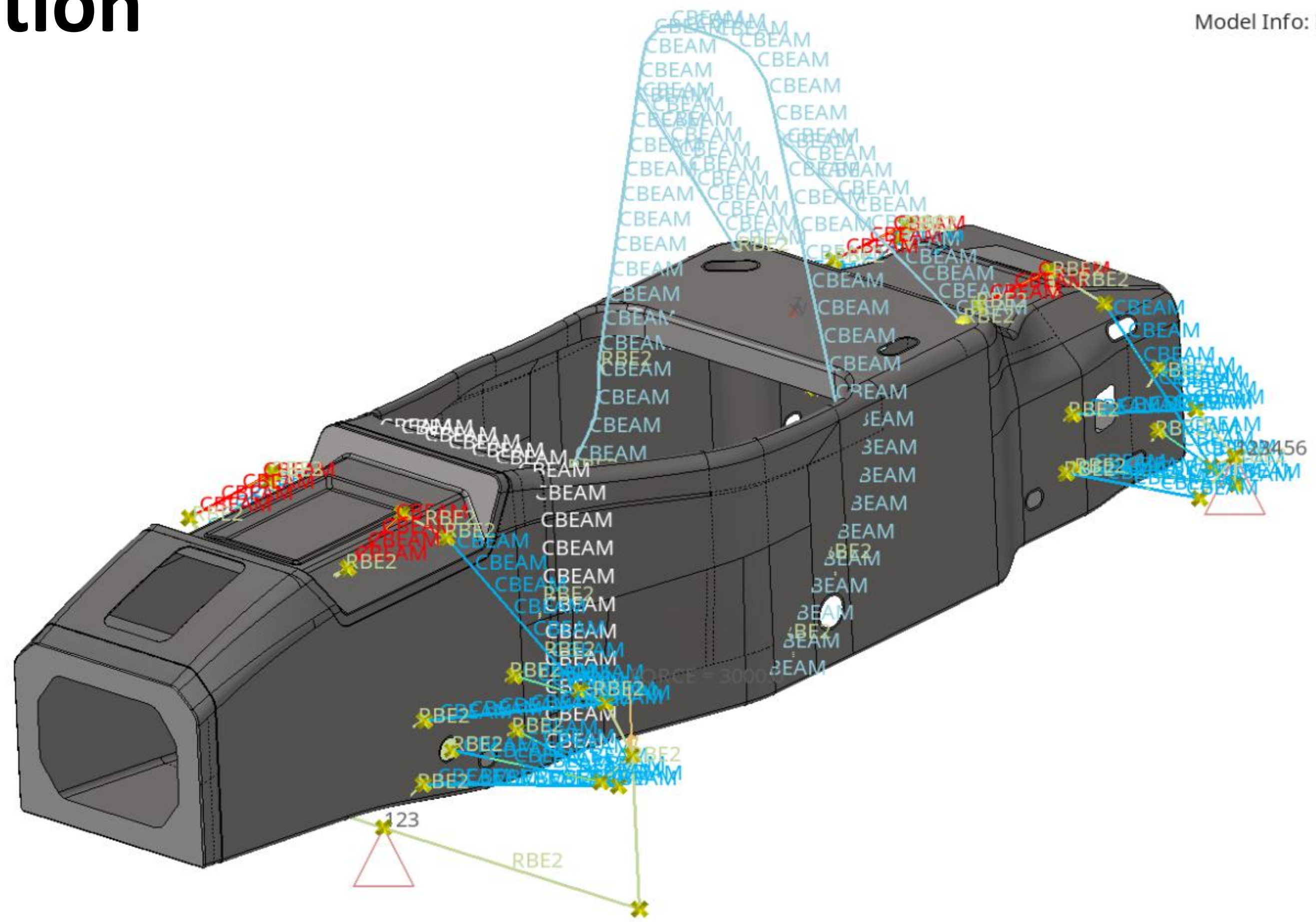
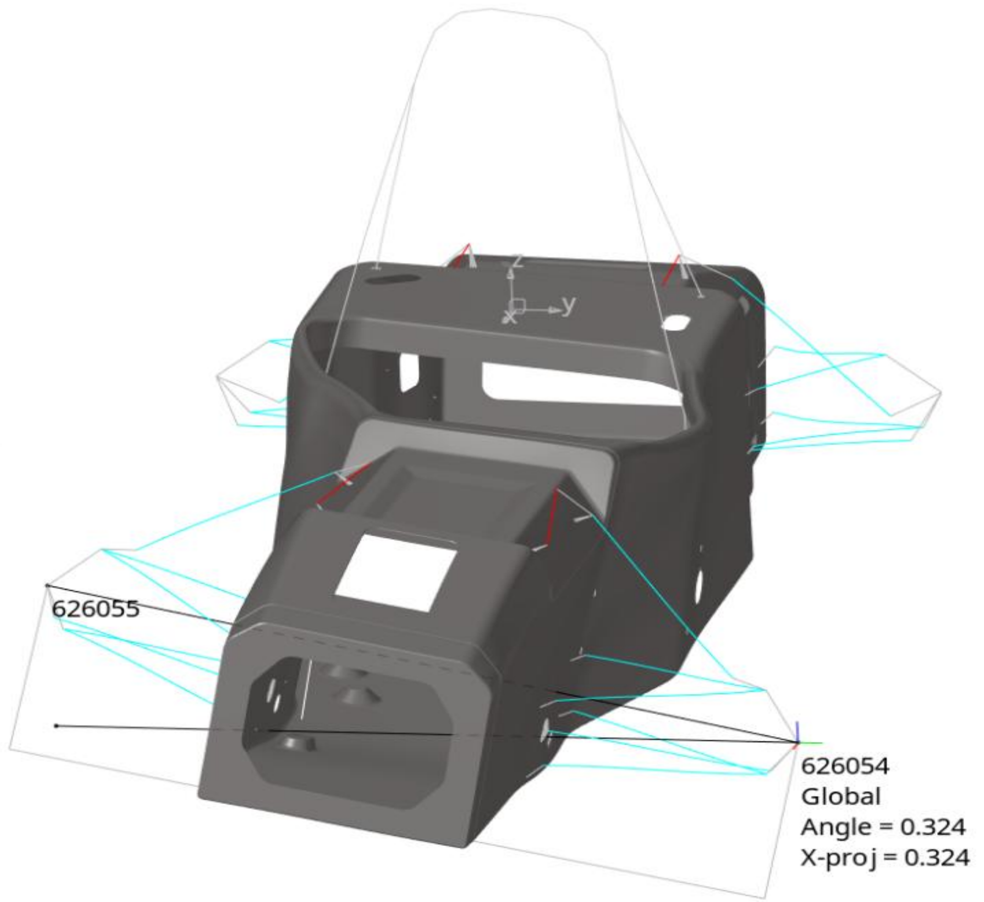
FORMULA SAE TEAM

Simulation

Model Info: E:/PBL/6_F-24_hypermesh/F-25 Torsional Stiffness try 1_1226.hm*



Front: X-Axis Rotating
Rear: Fixed Wheel Center



Relative Angle: 0.324

Torsional Stiffness:

1.190/2m x 3000N / 0.324 deg = 5,509 Nm/deg

4. Body Torsional Stiffness Test – This Week

KOOKMIN RACING HFP HIT FORMULA PROJECT FORMULA SAE TEAM

Result

Test no.	Mass [Kg]	Forces [N]	Displacement [mm]	Torsion Angle[°] - Sintheta	Torsion Angle[°] - R*theta	Torsion Radius [mm]	Torsional Stiffness - Sintheta	Torsional Stiffness - R*theta	Error from the average
1	7.56700	74.206	0.08	0.007703634243457	0.007703634220246	595	5731.407553Nm/deg	5731.407571Nm/deg	6.437850143%
2	11.63200	114.070	0.12	0.011555451408706	0.011555451330370	595	5873.550276Nm/deg	5873.550316Nm/deg	8.702098869%
3	7.57300	74.265	0.08	0.007703634243457	0.007703634220246	595	5735.952082Nm/deg	5735.952099Nm/deg	6.511978348%
4	3.50800	34.401	0.0405	0.003899964827011	0.003899964824000	595	5248.462604Nm/deg	5248.462608Nm/deg	-2.17140767%
5	11.63200	114.070	0.16	0.015407268626179	0.015407268440493	595	4405.162684Nm/deg	4405.162737Nm/deg	-21.73053548%
6	11.63200	114.070	0.143	0.013770246301255	0.013770246168690	595	4928.853365Nm/deg	4928.853412Nm/deg	-8.796665824%
7	15.10600	148.138	0.18	0.017333177259940	0.017333176995554	595	5085.158741Nm/deg	5085.158819Nm/deg	-5.452521675%
8	15.10600	148.138	0.164	0.015792450351469	0.015792450151505	595	5581.271804Nm/deg	5581.271874Nm/deg	3.921036056%
9	15.10600	148.138	0.17	0.016370222940748	0.016370222718024	595	5384.285735Nm/deg	5384.285808Nm/deg	0.405951915%
10	15.10600	148.138	0.162	0.015599859488736	0.015599859295999	595	5650.176396Nm/deg	5650.176465Nm/deg	5.092730767%
							5362.428124Nm/deg	**5362.428171Nm/deg**	

Improvements:

- The condition of applying torsional constraints to the front axle along the Y and Z axes needs to be changed to a condition that allows for three-axis rotational degrees of freedom → Bearing replacement.
- Due to the aging jig, the bearing center on the F-25 vehicle is not accurate.
- Jig optimization is required based on changes in the body shape.
- Due to measurement errors, a method for verification through multiple tests is necessary

4. Body Torsional Stiffness Test – This Week

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Cost

Currently creating a BOM to review the feasibility of introducing the test for the HIT team.

Front Anti Roll Bar System – Bill of Materials

Title	Description	Part # Base	Part # Suffix	Quantity
Front Anti Roll Bar System		A7002	AA	1

Edit Info

Assembly Cost $97.77
Total $97.77

Parts

	Part	Part #	Op Num	Part Cost	Quantity	Subtotal
1	Anti-Roll Bar	P70021-AA	1	1.63	1	1.63
2	Anti-Roll Bar Adaptor	P70022-AA	2	1.17	2	2.34
3	Anti-Roll Bar Bushing	P70023-AA	3	0.81	2	1.62
4	Anti-Roll Bar Mount Upper	P70024-AA	4	1.56	2	3.12
5	Anti-Roll Bar Mount Lower	P70025-AA	5	2.3	2	4.60
6	ARB Adjuster	P70026-AA	6	6.62	2	13.24
7	ARB Drop Link	P70027-AA	7	20.43	2	40.86
8	Spacer Washer	P70028-AA	8	0.21	8	1.68

Add Part

Subtotal $69.09

Materials

Material	Use	Op Num	Size 1	Size 2	Area Name	Area	Length	Density	Quantity	Unit Cost	Subtotal
No data available in table											

Add Material

Subtotal $0.00

Processes

	Process	Use	Op Num	Quantity	Multiplier	Mult. Val.	Unit Cost	Subtotal
8	Assemble, >20 kg, Line-on-Line	Monocoque & Anti-Roll Bar Mount Lower	5-1	1	Repeat 2	2	3.75	7.50
9	Assemble, 1 kg, Line-on-Line	Anti-Roll Bar & Anti-Roll Bar Bushing & Anti-Roll Bar Mount Upper	1,3,4,5-1	1	Repeat 2	2	0.13	0.26
10	Wrench <= 6.35 mm	To fasten M6 Bolt, Using 5mm Hex Wrench	1,3,4,5-2	2	Repeat 2	2	1	4.00
11	Reaction Tool <= 25.4 mm	To fasten M6 Nut, Using 10mm Wrench	1,3,4,5-3	2	Repeat 2	2	0.25	1.00

America Formula SAE Cost E-BOM System

Included Items

1. **Assembly & Parts Info**
2. **Material**
   - Test Zig Material
   - Measurement Equipment
3. **Processes**
   - Set up for Manufacturing
   - Labor
   - Outsourcing
4. **Fasteners**

-> *It is possible to analyze the cost distribution for each item and assess the feasibility of implementation*

5. Data Logging Analysis

For HIT Formula Project

- Use the same manufacturer's data logger as KMU. The powertrain data, tire temperature data, and other technologies are superior to KMU.
- There are areas that need improvement in terms of logger, sensor use, and packaging.
- Render driving data on onboard video to provide objective feedback.

For KOOKMIN RACING

- Use the same manufacturer's data logger as HIT. The chassis data logging technology and analysis are superior to those of HIT.
- A comparative analysis of the presence or absence of body members in the HIT vehicle will be conducted through driving data

For All Team

We need to explore a method to evaluate the changes in vehicle dynamic performance based on body stiffness.

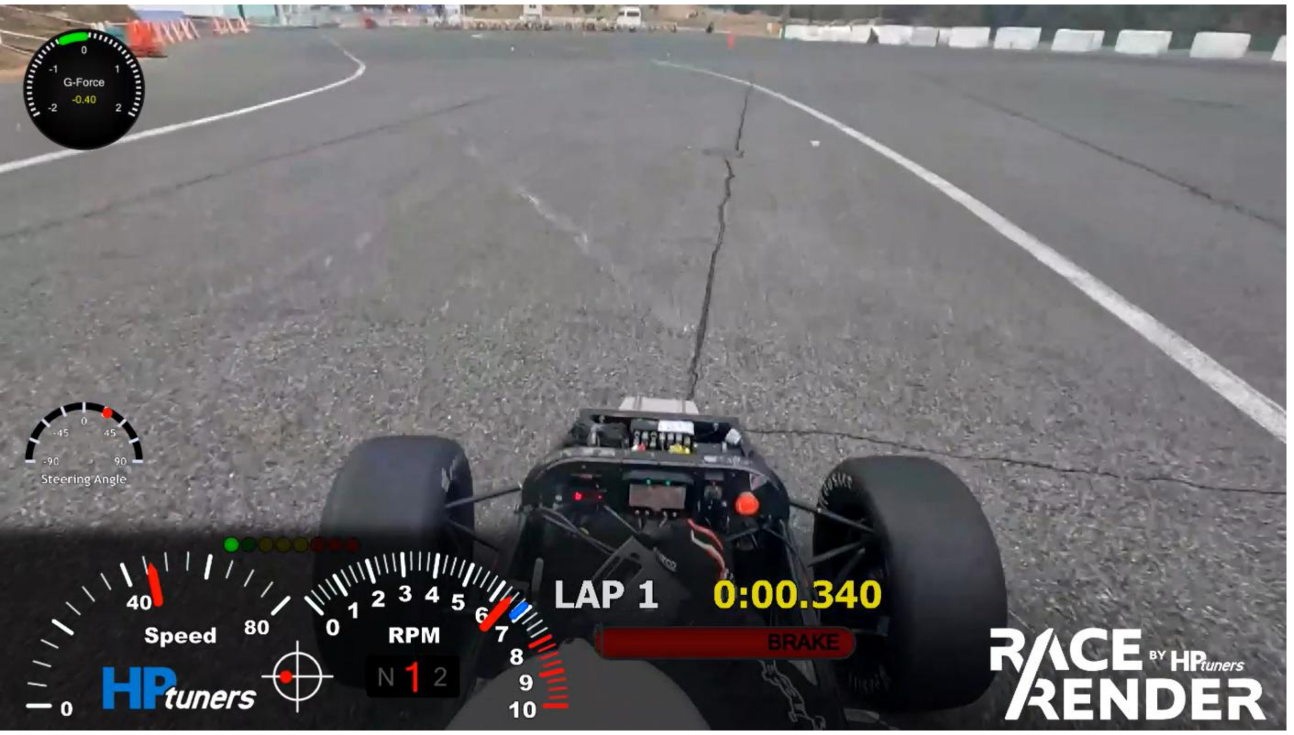
5. Data Logging Analysis – Last Week

KOOKMIN RACING
HFP HIT FORMULA PROJECT
FORMULA SAE TEAM

Analysis of Under Member Test

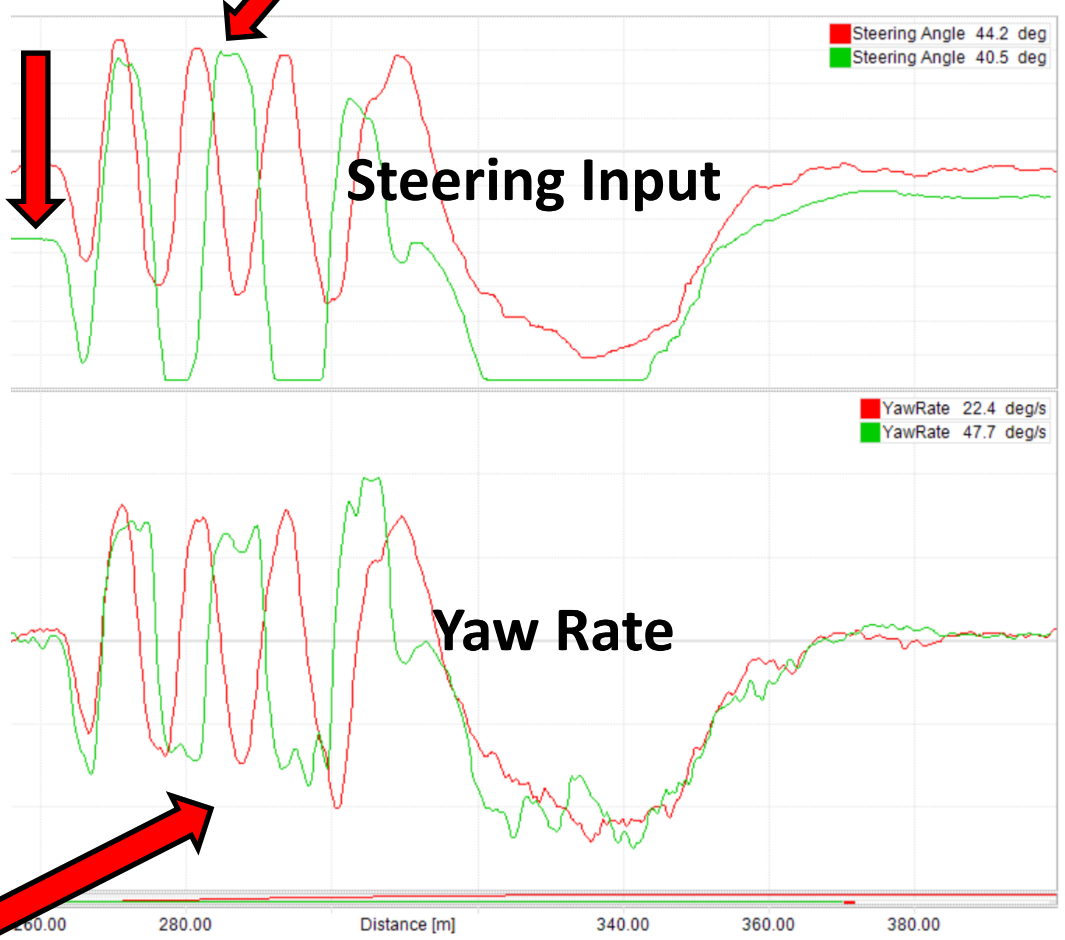
Red Line: With Floor Member
Green Line: Without Floor Member

About 40° offset

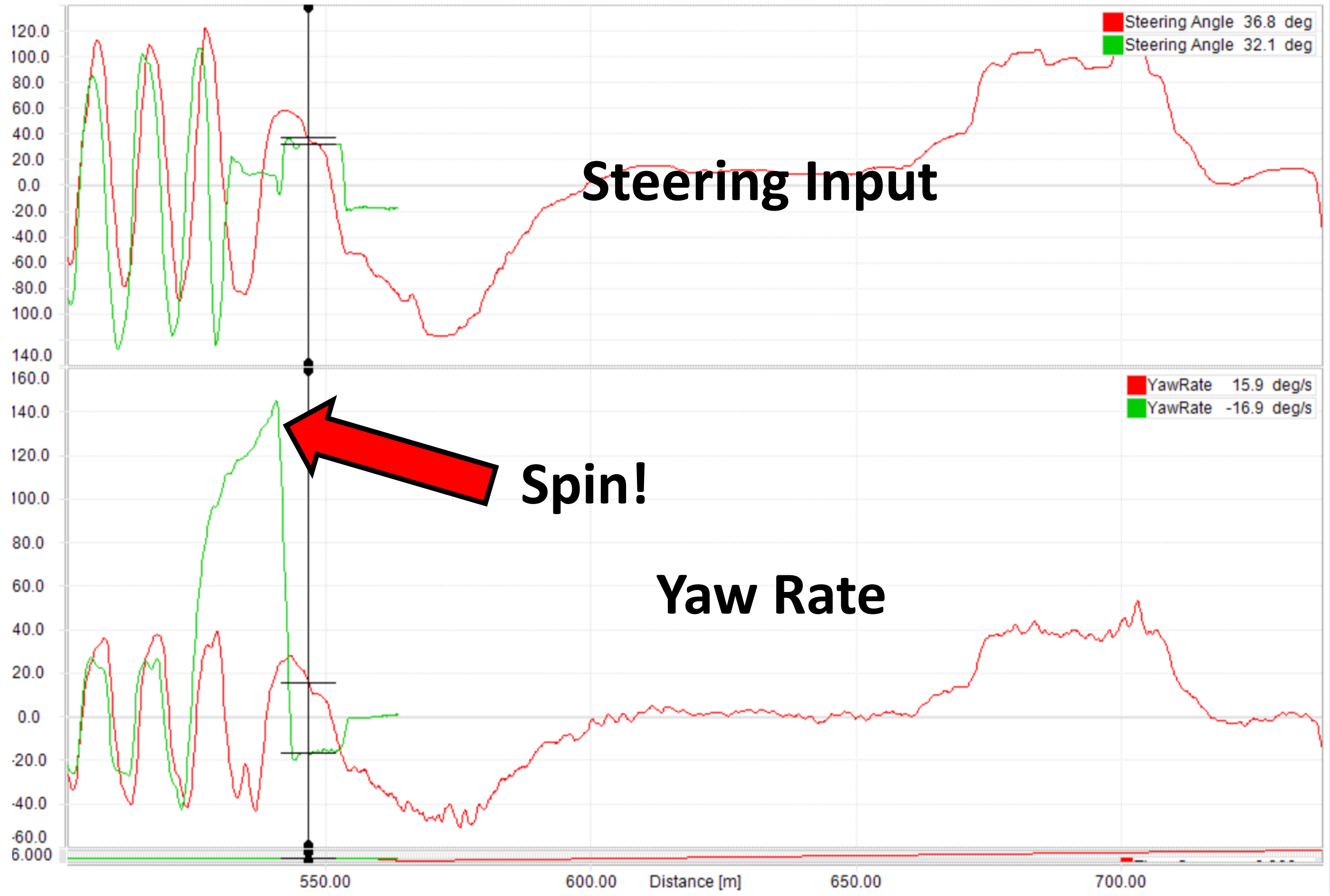


Implementing Driving Data on the Onboard

Based on the video analysis, sensor errors occurred in that area. However, the steering angle movement ranges from -90 to 90 degrees, showing a greater amplitude than the Red Line test.



1st Test



2nd Test

More Vibration in that
-> The body rigidity is expected to have significantly decreased after the removal of the floor member

As a result, the HIT team experienced spins during the same test when the body stiffness was weak, and we aimed to prove this through driving data analysis.
As a result, we were able to find evidence that aligns with the actual test results

5. Data Logging Analysis – This Week

KOOKMIN RACING HFP HIT FORMULA PROJECT FORMULA SAE TEAM

Re-Simulation of Test

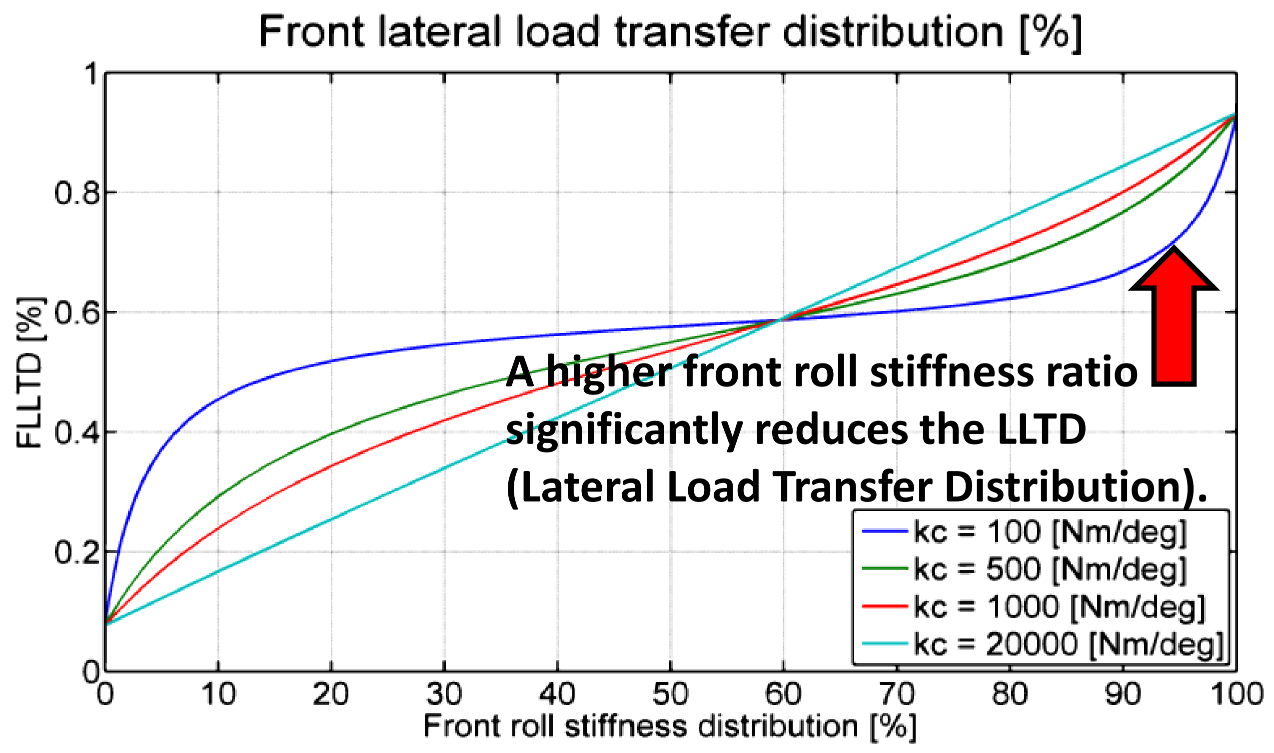
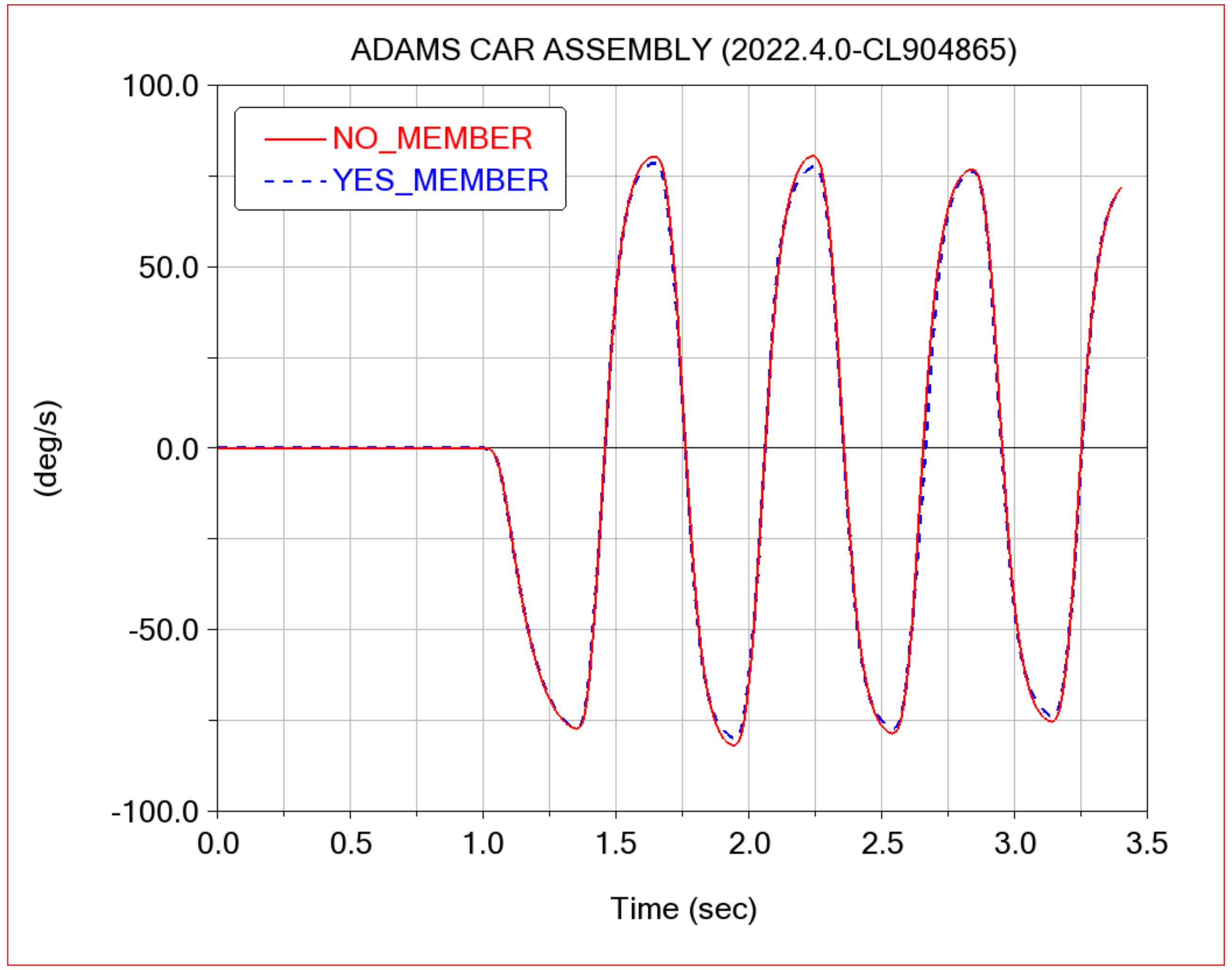


Figure 2.6: *Front lateral load transfer distribution model, for a flexible body*



Analysis conditions closely resemble actual driving situations, but the results are inconclusive,,,

Mazda's Feedback

It is common for body stiffness evaluation methods to be predominantly subjective.
However, when asked about research on quantitative evaluation methods or ways to verify data, no clear answer was provided.

As a commercial vehicle manufacturer, they can conduct blind tests and test various models, which is challenging at the student formula level.

Nevertheless, their pursuit of the '人馬一體' concept aligns with our goals
—> minimizing unnecessary load transfers and developing a chassis setup that closely matches the desired overall vehicle yaw rate

6. Conclusion

Conclusion of Subjects

KOOKMIN RACING
HFP HIT FORMULA PROJECT
FORMULA SAE TEAM

1. **Vehicle Dynamics Simulation**

   We shared a technical approach to evaluate the impact of body stiffness on vehicle dynamic performance.
   Through this, we believe both teams will be better positioned to determine the design direction of the next vehicle.
   To consider body stiffness more accurately, it is necessary to research flexible body modeling technology.

2. **Targeting Body Torsional Stiffness**

   During the vehicle concept selection stage, we developed a numerical sheet to determine the target body stiffness.
   This is expected to enable the production of an efficient body.

3. **Body Torsional Stiffness Simulation**

   We conducted simulations considering all body stiffness analysis conditions prioritized by both teams.
   Despite the differences in the design tools used by the two teams, we overcame this challenge and integrated the analysis into a single tool.

4. **Body Torsional Stiffness Test**

   We transferred technology to the HIT team through hands-on experience in measuring the vehicle's body stiffness.
   In addition to this test, it is necessary to research measurement methods that better reflect real driving conditions.

5. **Data Logging Analysis**

   We objectively analyzed HIT's experiment and transferred rendering technology.
   Analyzing body stiffness through driving data is very challenging. Research on enhancing driver feedback techniques or converting subjective feedback into data also seems intriguing.

Conclusion of PBL (HIT Formula Project)

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HFP HIT FORMULA PROJECT
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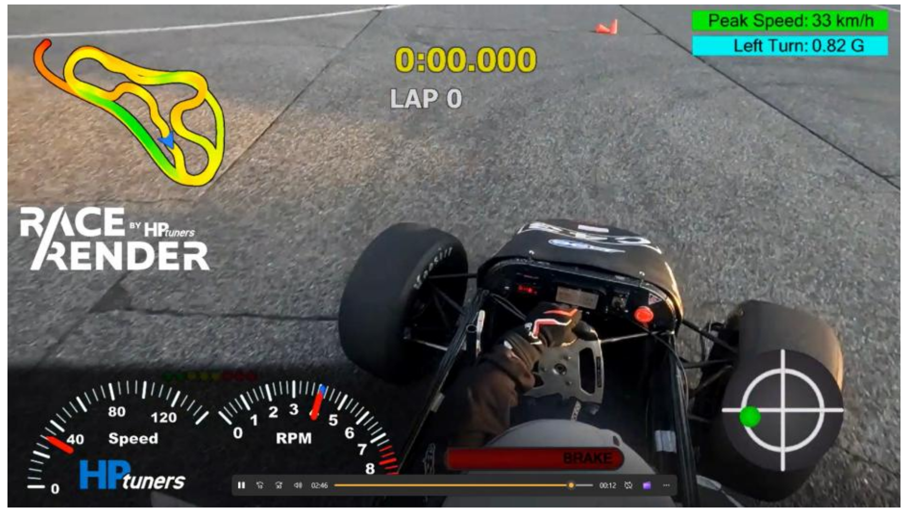
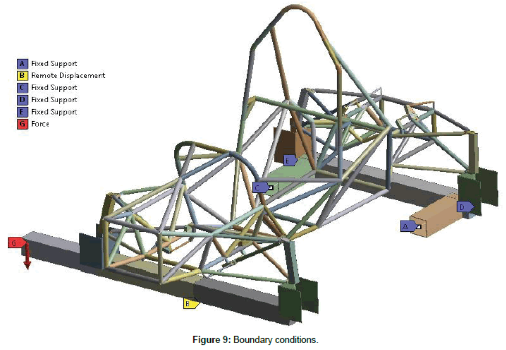
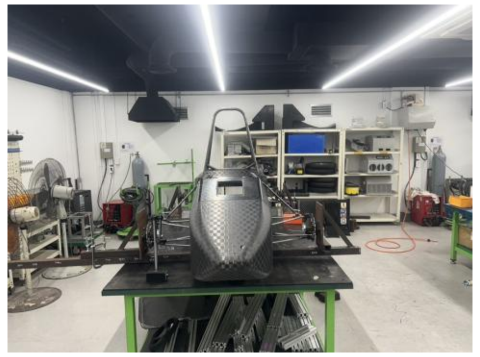
CR-24

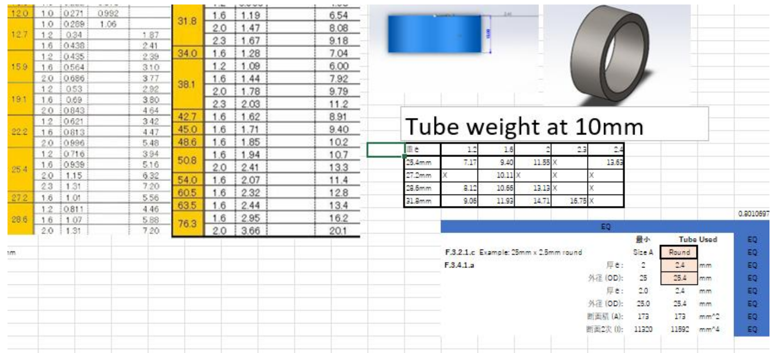


Improving the analytical capabilities of your data logger





Simulation Optimization



Pipe structure optimization

Vehicle Production

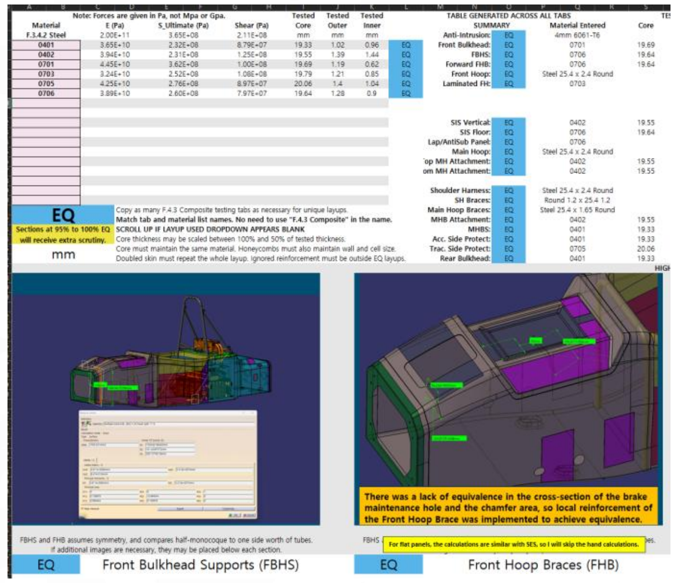
CR-25

Conclusion of PBL (KOOKMIN RACING)

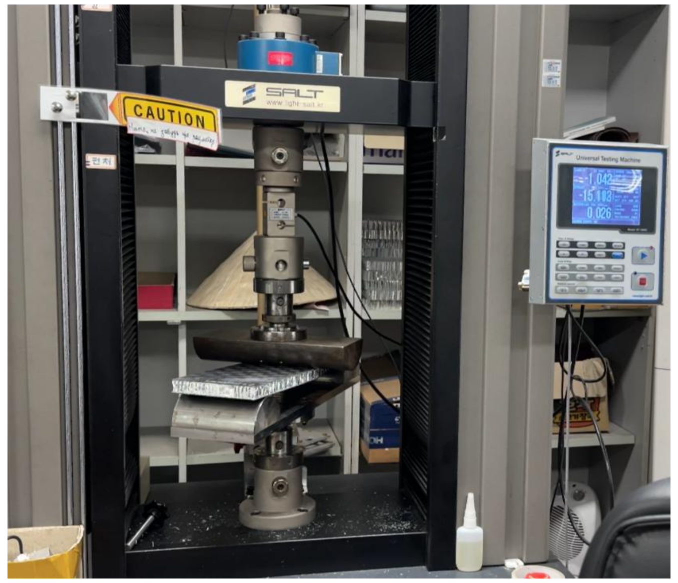
Global Competition in after 6 years
First Time to Formula SAE Electric


FORMULA SAE
Rules 2025
Version 1.0
31 Aug 2024

New Rule



SES Document

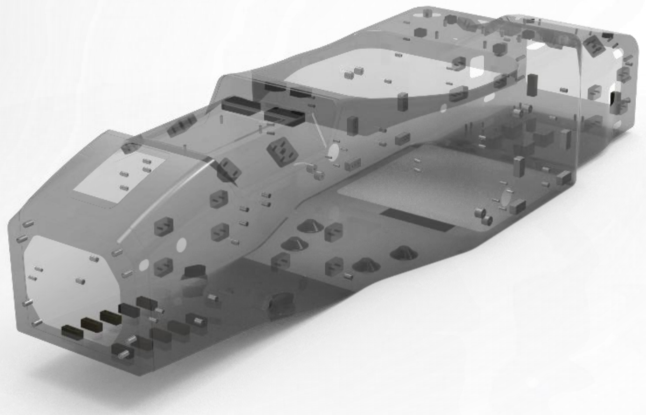


Panel Test

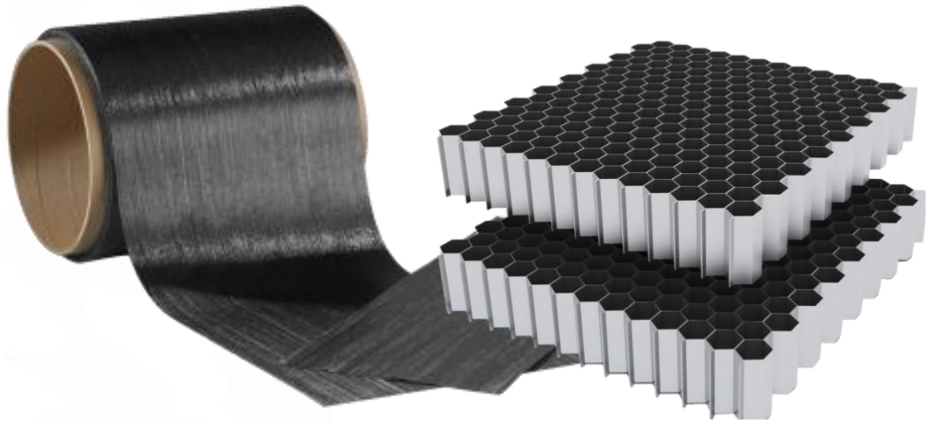
Manufacturing

-> Hard to consider the ‘Pure Performance’

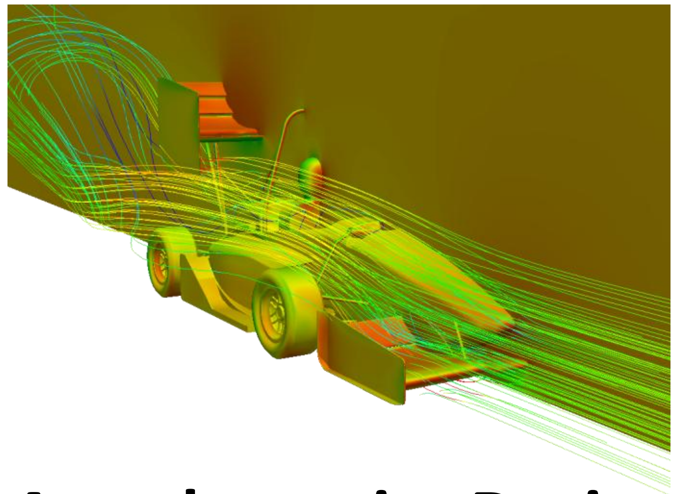
After 2025 PBL,,,



Rigidity Design Update



Material Change for Lightweight



Aerodynamics Design

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Thank you for Watching!

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