Vehicle Dynamic Brief

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UCDAVIS
COLLEGE OF ENGINEERING

Brief

- Using FE3 (last year car) to validate CarSim
- Damper tuning
- Frequency response of sprung/unsprung mass to road input analysis
- Comparing the handling characteristic to the different suspension setup
- Validation of FE4
- Application of a driving simulator to support vehicle design
- Goal of future

Using FE3 to Validate CarSim

Using FE3 validate CarSim

Test car on Blue Max Karting Track

Using FE3 validate CarSim

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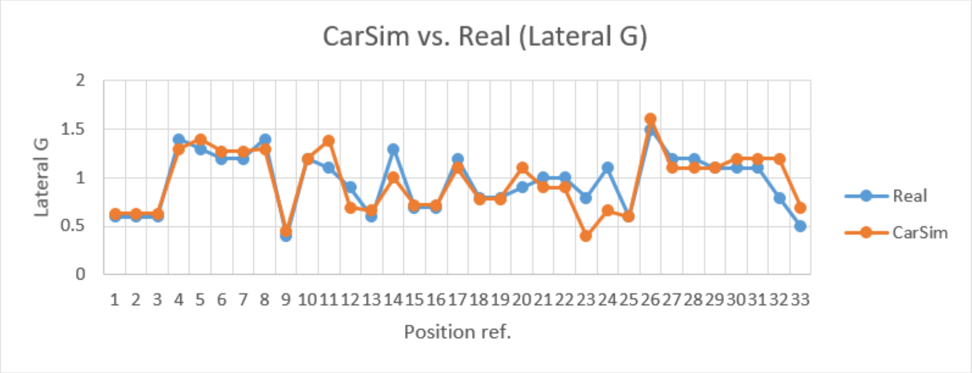
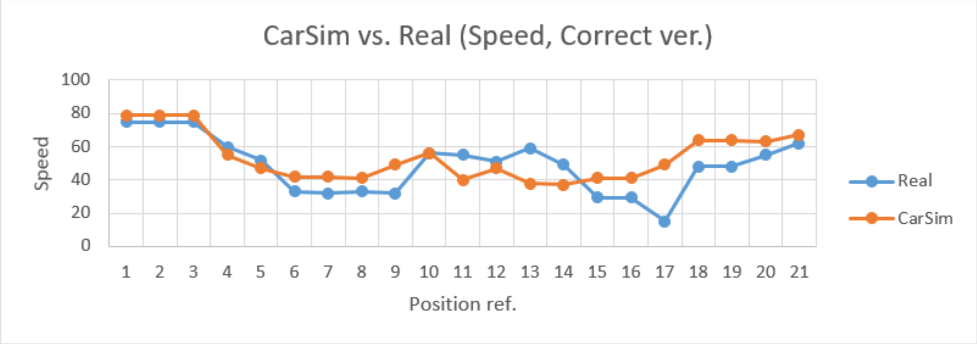
Compare CarSim (left) to real(right) at corners

Using FE3 validate CarSim

Result

- Lateral Acceleration data matched quite well
- Velocity data didn't quite match since the evaluation (Z-axis) profile of track didn't count in simulation
- Meanwhile, the velocity data were recorded by GPS which suffered by time delay.





Damper Tuning

Damper Data

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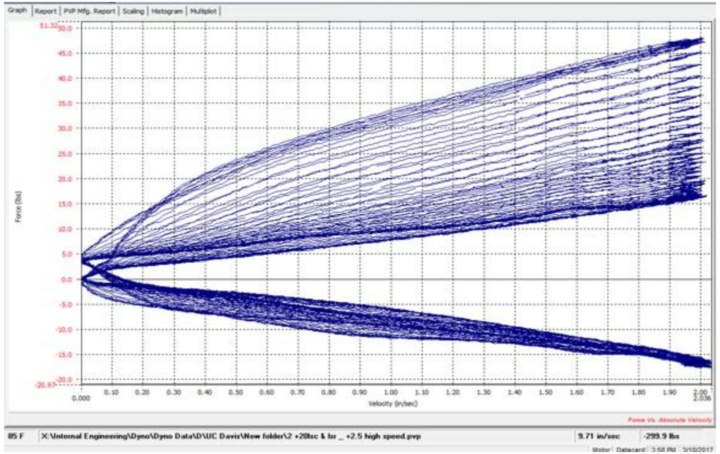
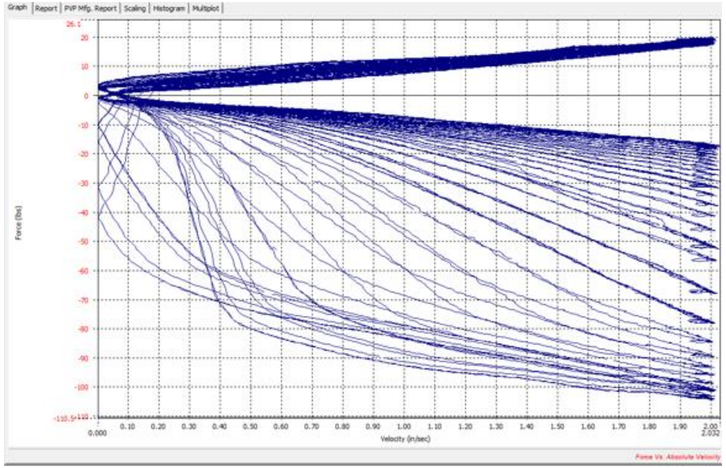
Damper Data with different adjustments



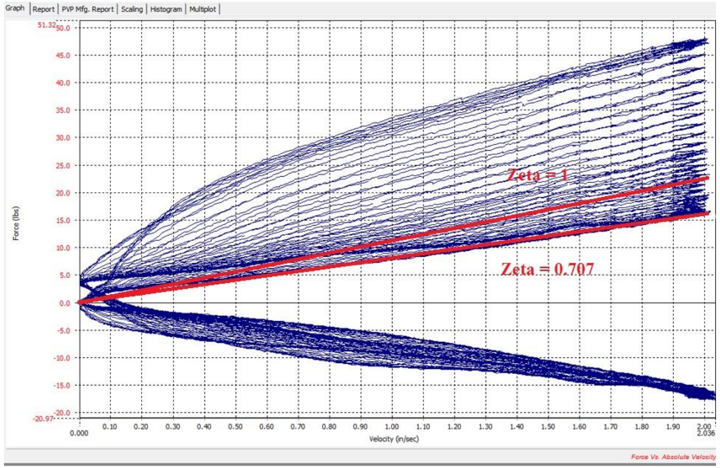
Compression



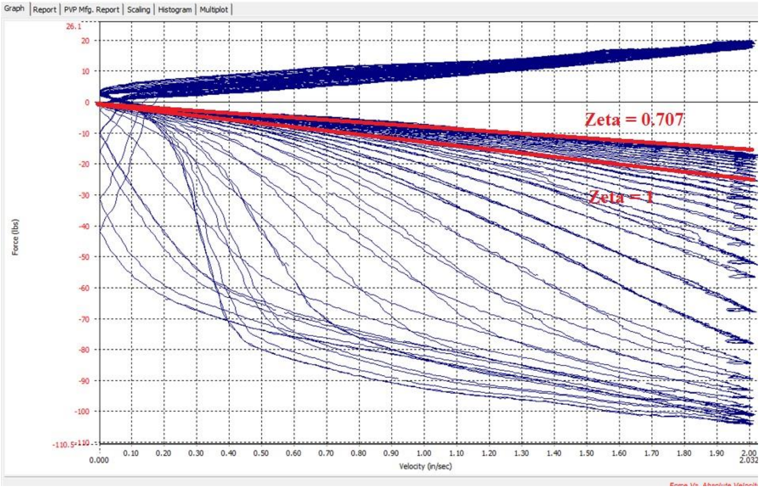
Extension

Damper Data

Bounded between 0.707 and 1



Compression



Extension

Baseline Setting

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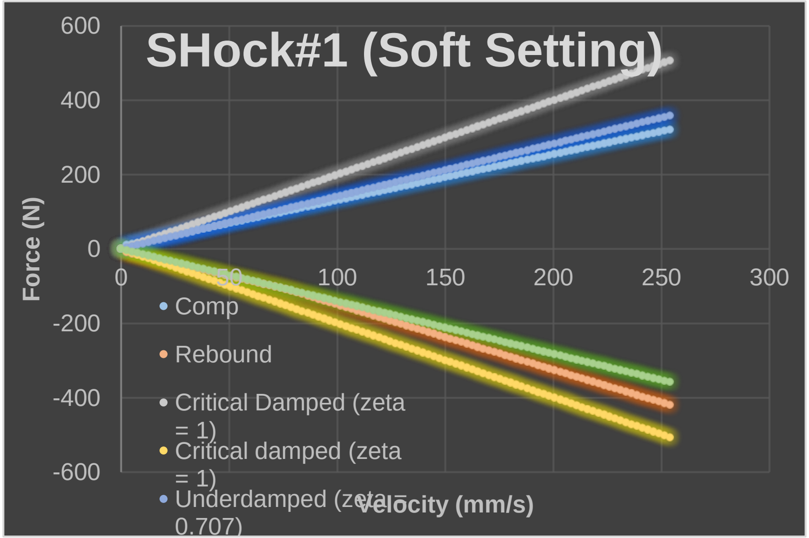
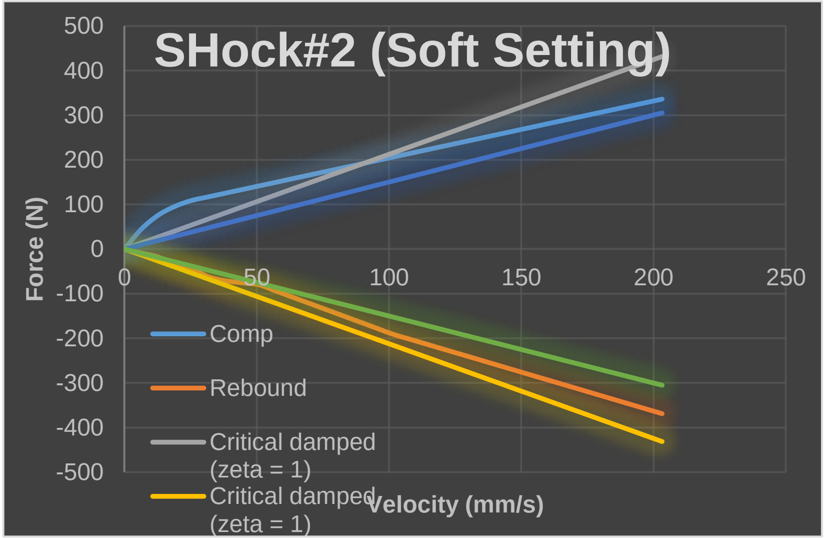
Rear Shock

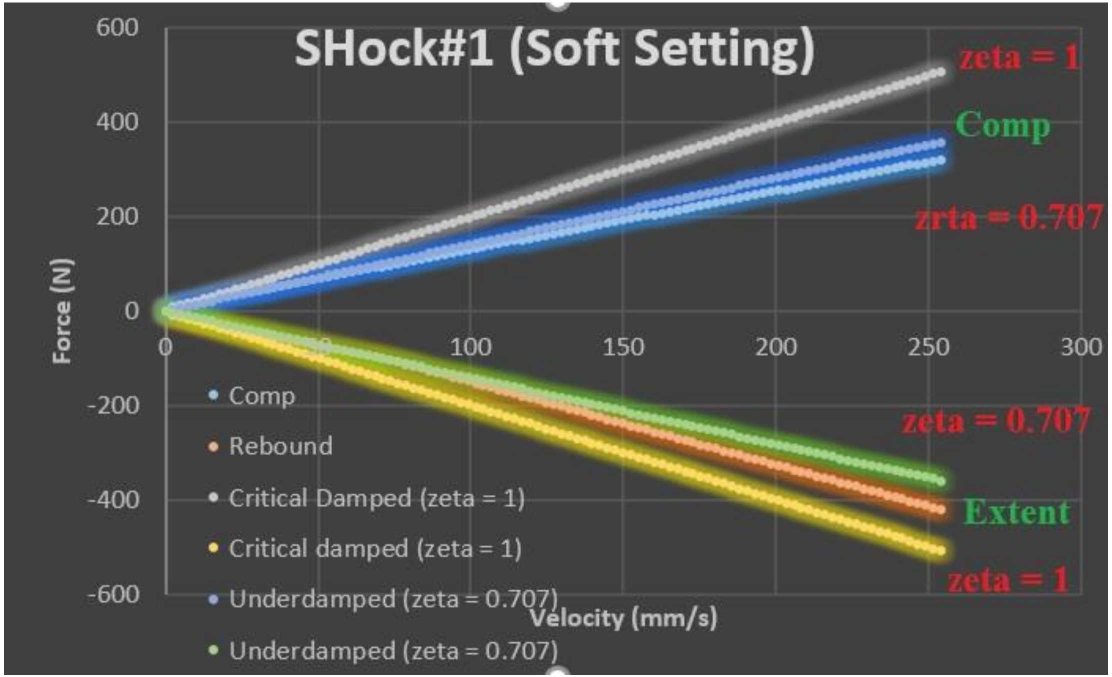


Front Sock



Baseline Setting

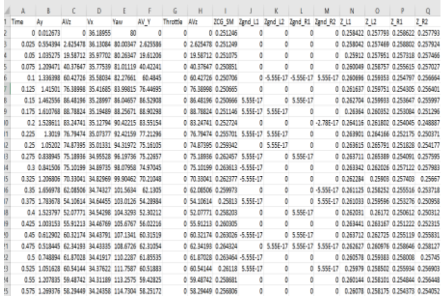
Make the damping coefficient bounded between 0.707 and 1



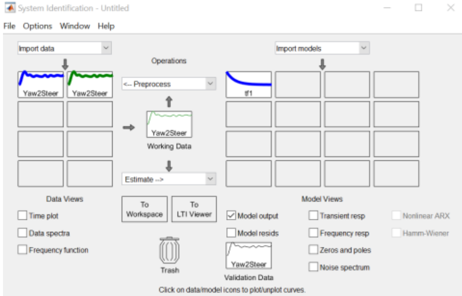
Frequency Response of Sprung & Unsprung Mass to Road Input Analysis

Procedure

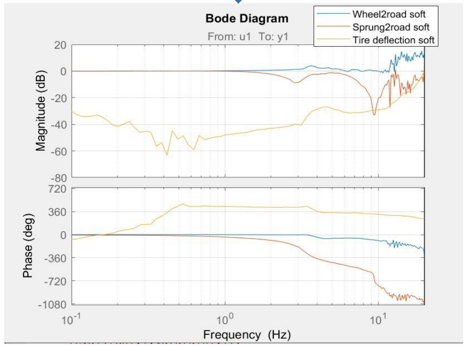
1, CarSim simulation



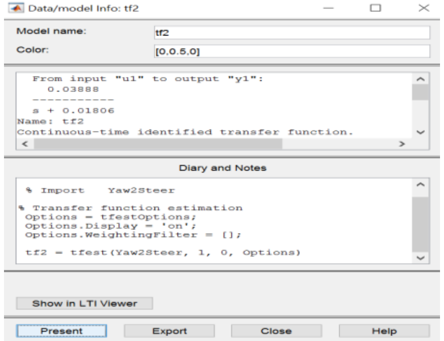
2, Export data to Excel



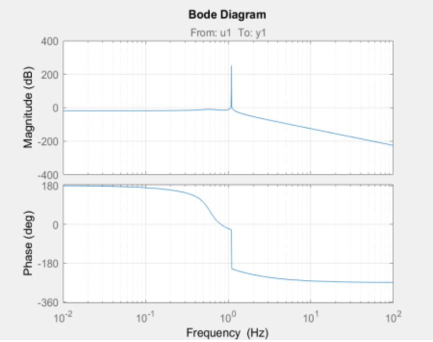
3, Convert to transfer function on Matlab



4, Bode plot analysis

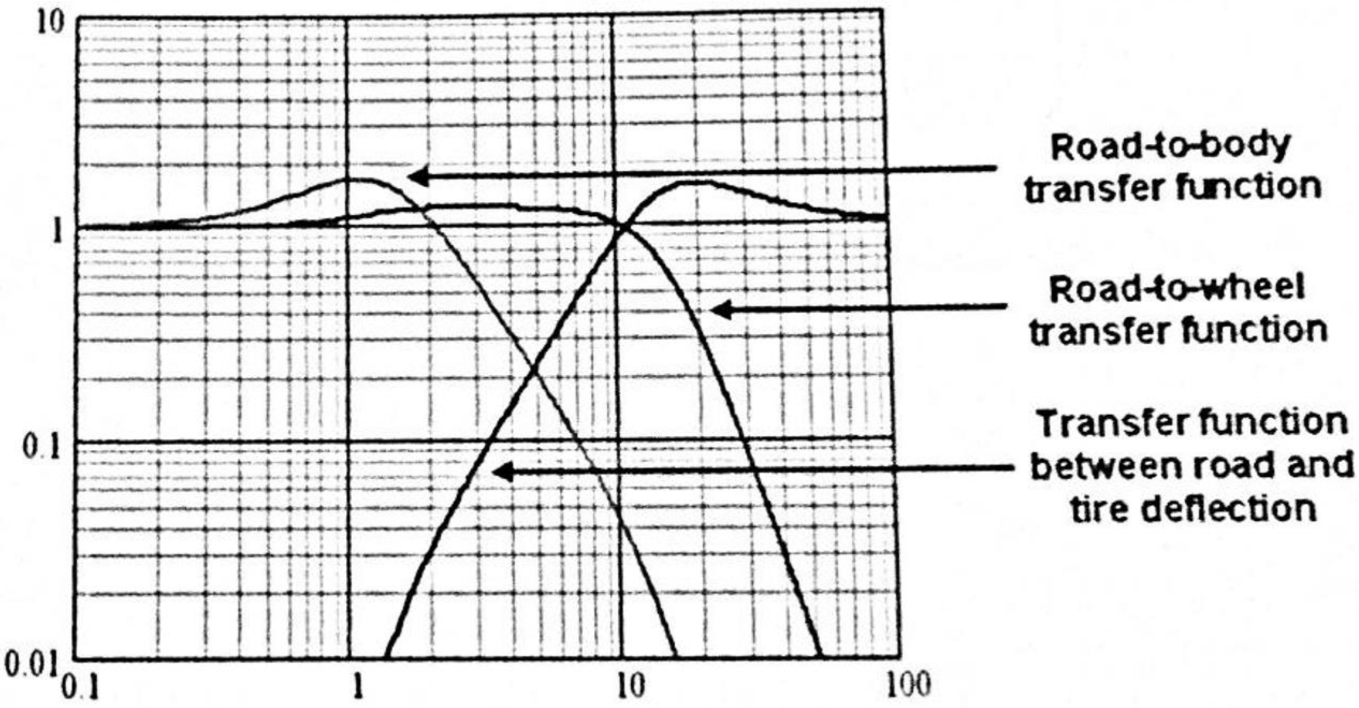


5, Simplify transfer function



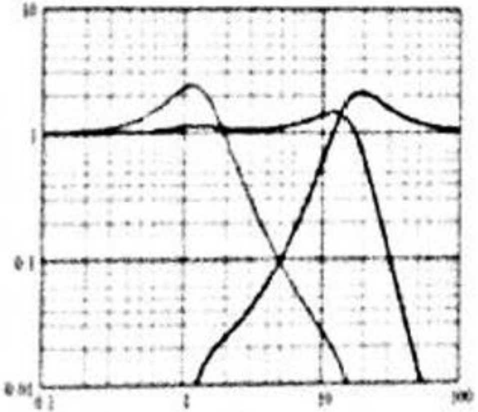
6, Bode plot analysis (simplified)

Suspension System Transfer Function (Demo)

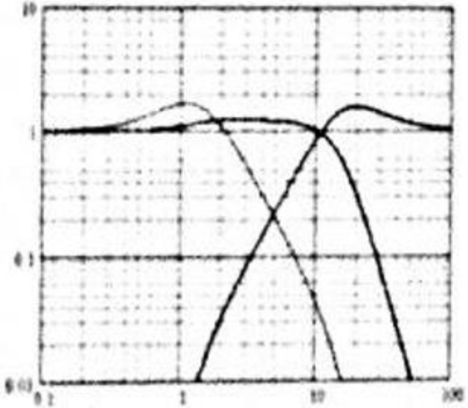


Note: reference#2

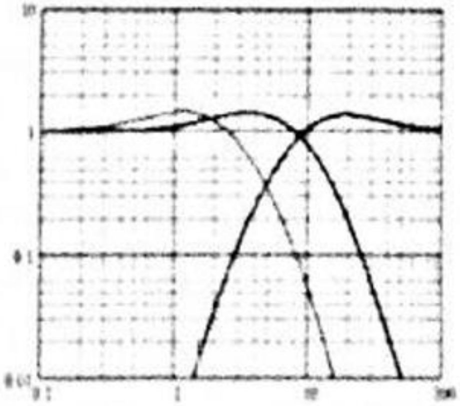
Compare Different Damping (Demo)



Soft damping
(2500 Ns/m)



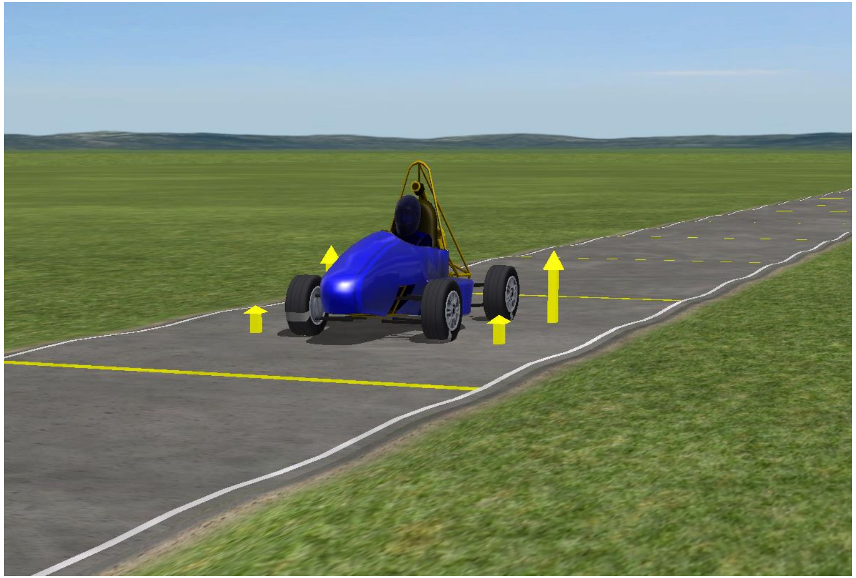
Normal damping
3800 Ns/m



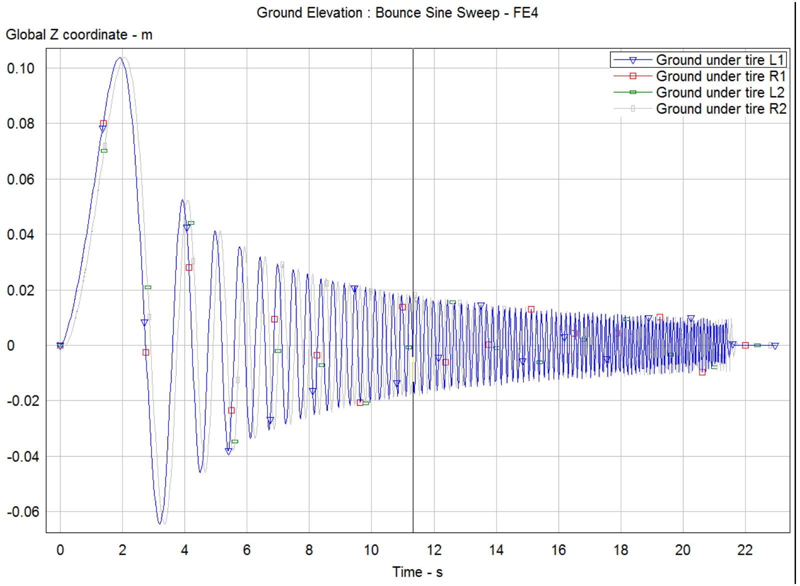
Hard damping
(4800 Ns/m)

Note: reference#2

Bounce Sine Sweep Test (FE4)



Test FE4 on Bounce Sine Sweep



Elevation of the road on test

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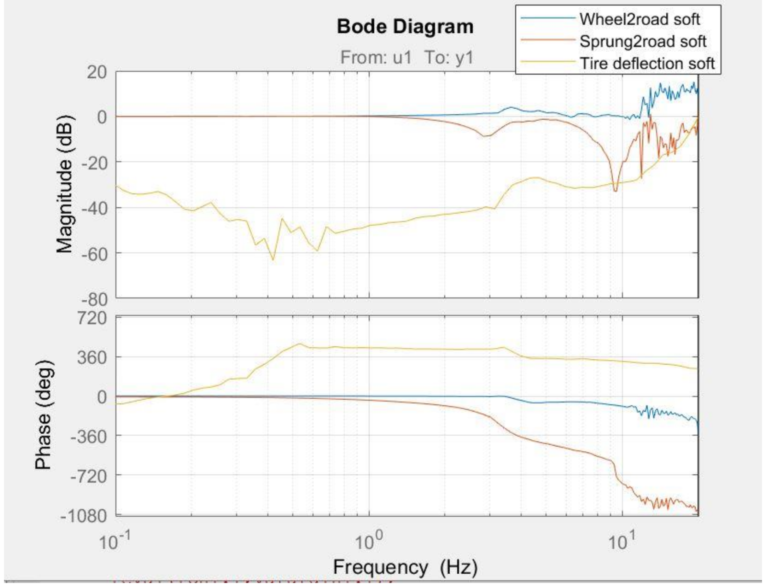
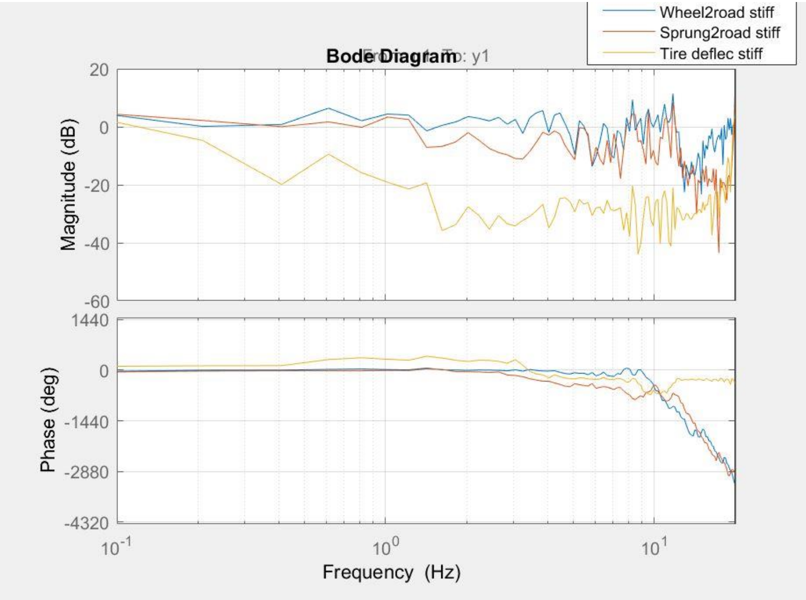
Compare Different Damping (FE4)

Baseline



Stiff Damping



Baseline setting follows the target (0 dB) very well

Suspension Grip Potential (Demo)

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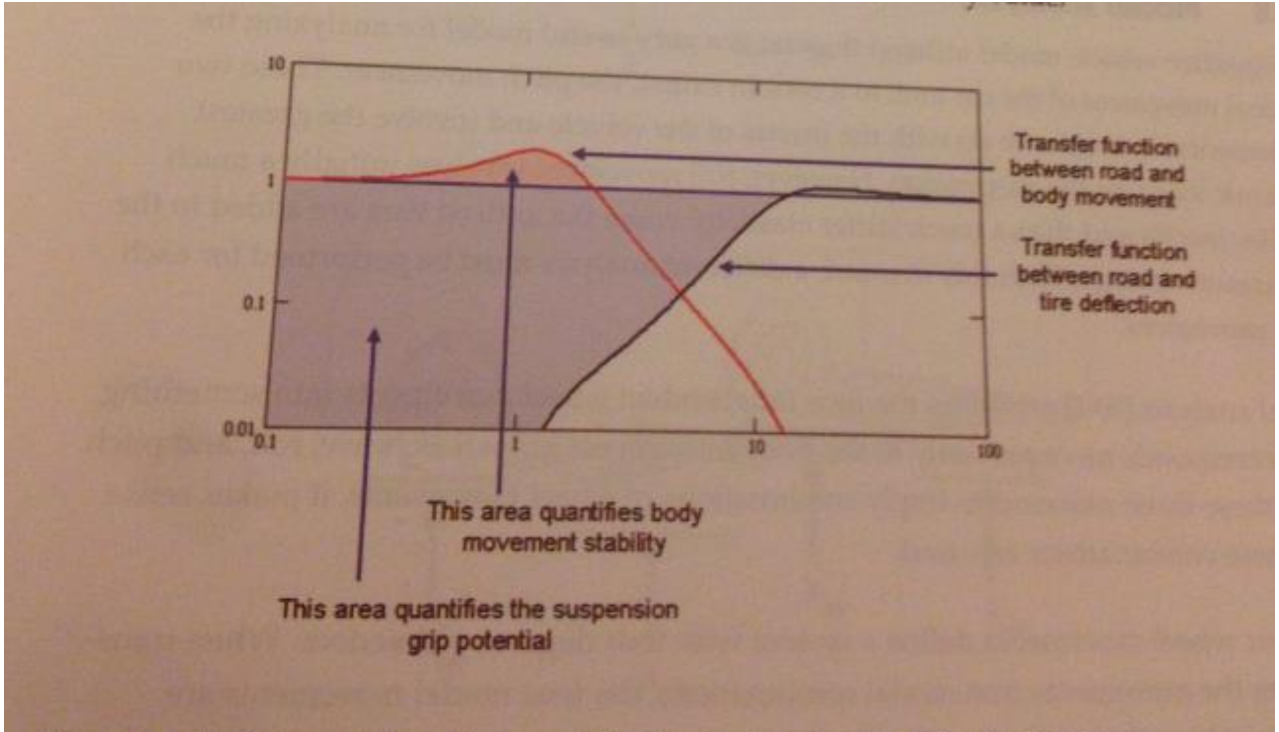


Figure 12.15 Grip and stability quantification using the transfer functions

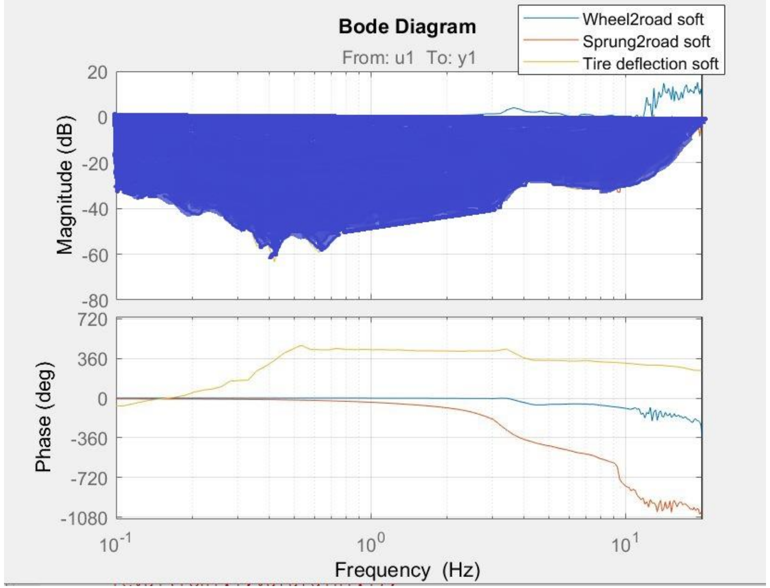
Suspension Grip Potential

Body Movement Stability

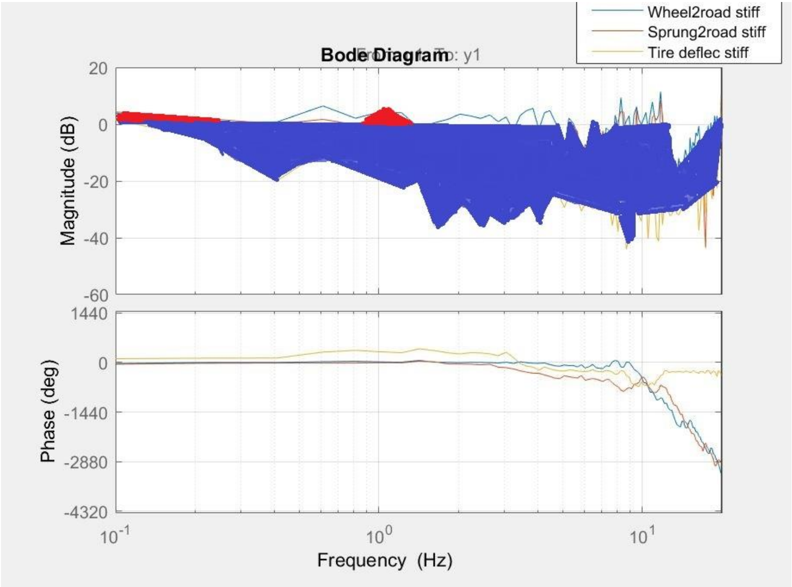
Note: reference#2

Suspension Grip Potential (FE4)

Baseline



Stiff Damping

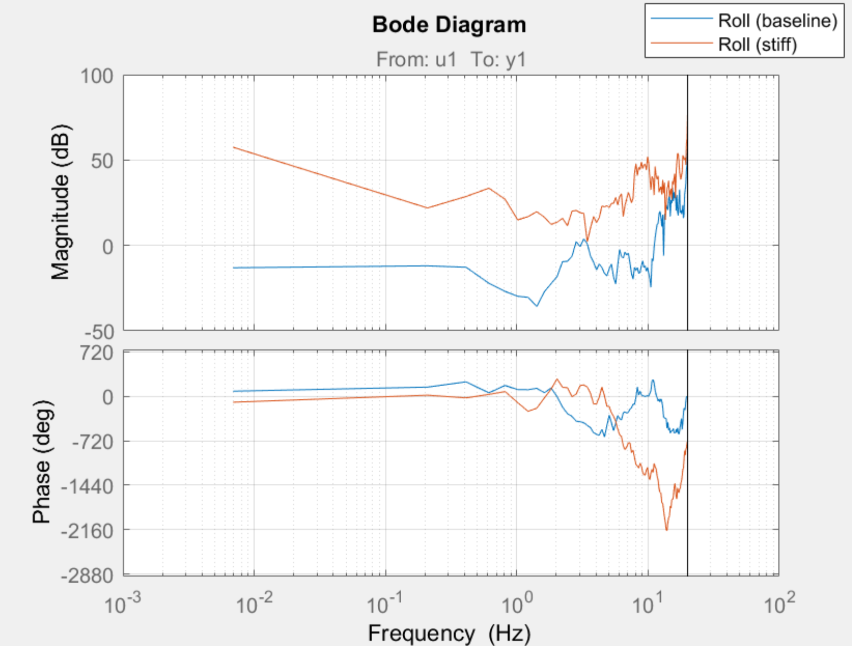


Baseline setting has greater suspension grip potential (larger area in blue color) and better body movement stability (smaller area in red color)

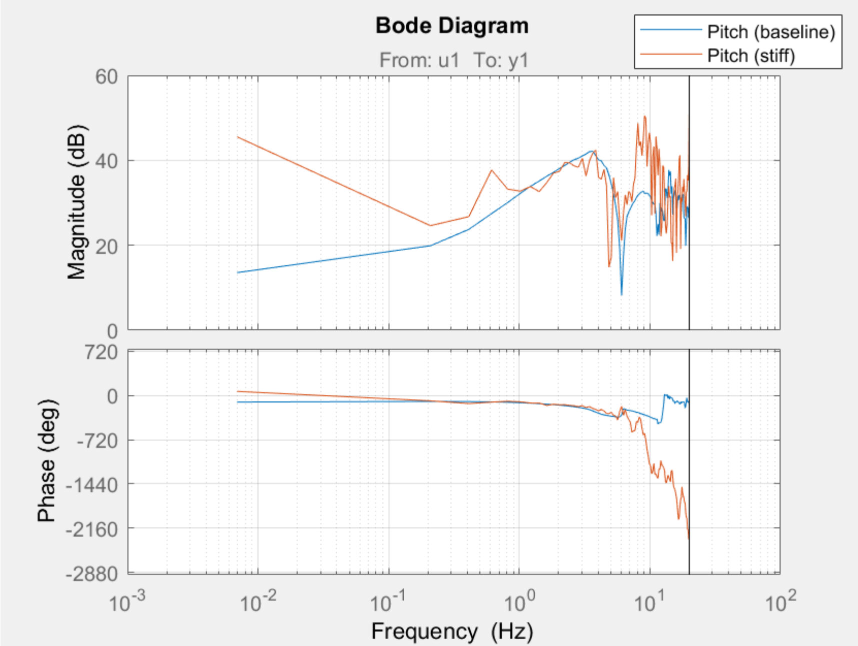
Suspension Grip Potential

Body Movement Stability

Roll and Pitch Frequency Response (FE4)



Roll frequency response (baseline)



Pitch frequency response (stiff)

Compare in Different Road Condition

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International Roughness Index (IRI)

- Freeway – 0.87 m/km
- Country road – 1.45m/km
- Rough road – 3.82 m/km

Note: reference#3

Compare in Different Road Condition

UCD formula RACING

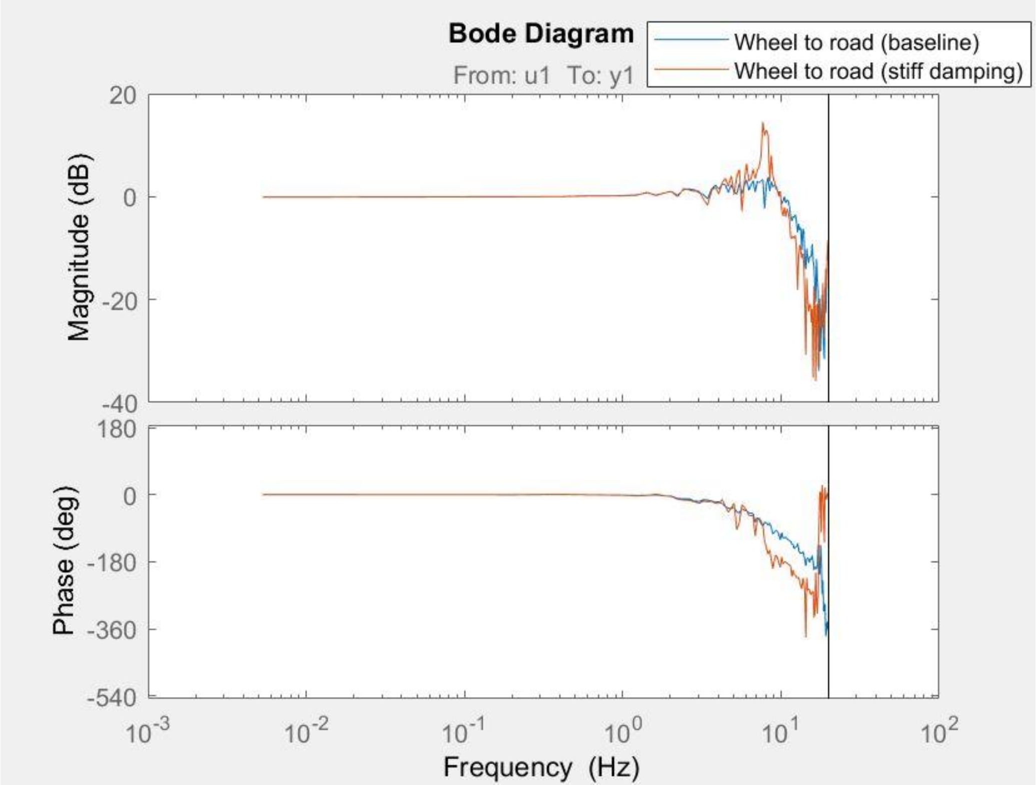
Condition:

- Road: freeway
- IRI: 0.87 m/km
- Test speed: 112 km/hr

Compare peak value:

- Baseline: 3.7 dB
- Stiff damping: 14.5 dB

Baseline is better!



Compare in Different Road Condition

UCD formula RACING

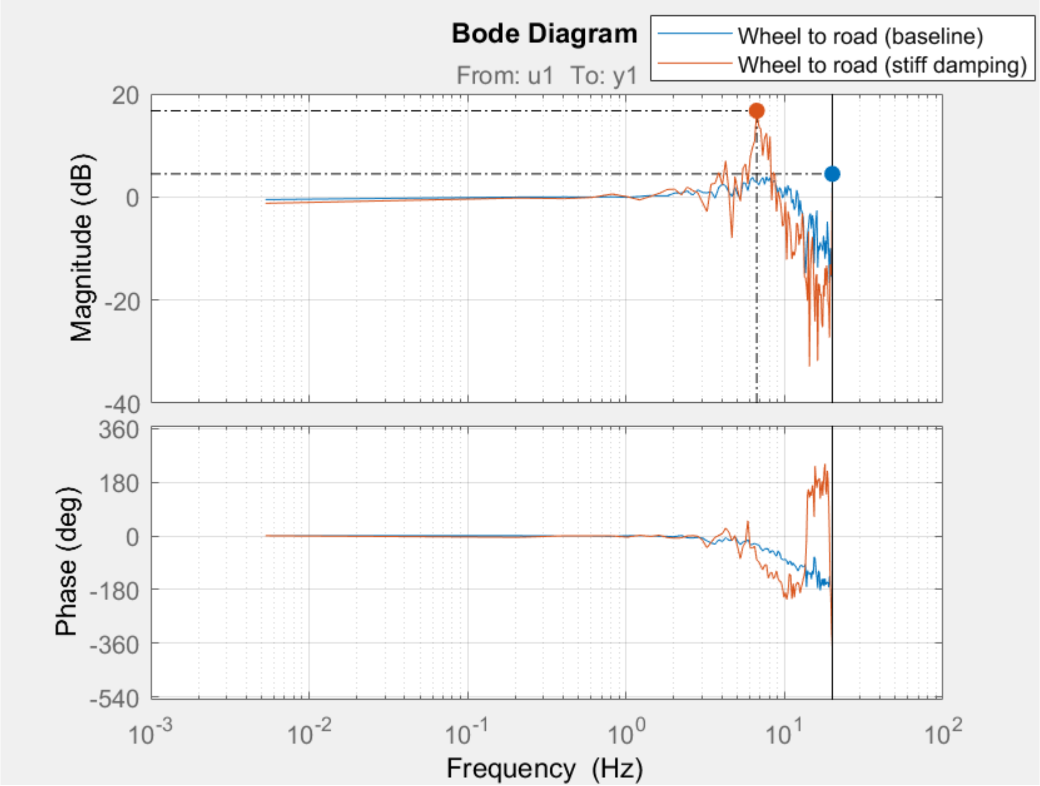
Condition:

- Road: rough road
- IRI: 3.82 m/km
- Test speed: 112 km/hr

Compare peak value:

- Baseline: 4.5 dB
- Stiff damping: 16.7 dB

Baseline is better!



Comparing the Handling Characteristic to the Different Suspension Setup

Theory

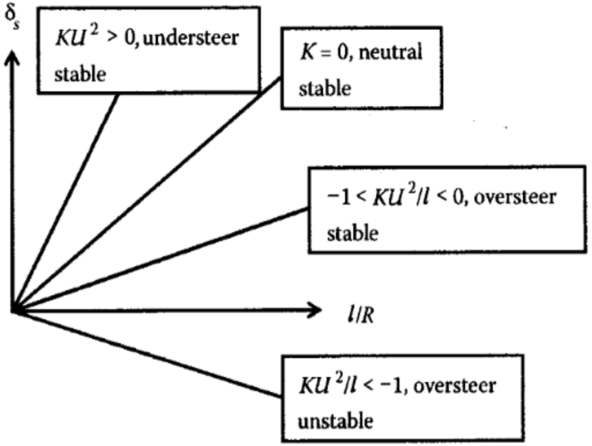


FIGURE 6.14
Steer angle as a function of wheelbase divided by turn radius.

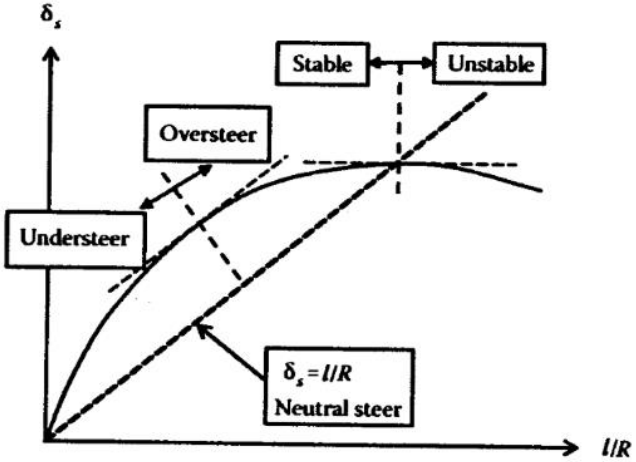
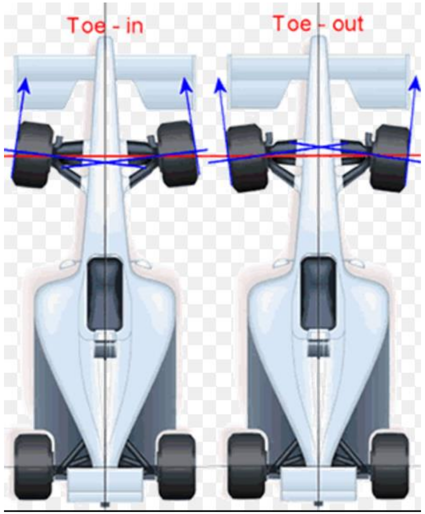


FIGURE 6.15
Steer angle as a function of l/R for a nonlinear case.

Note: reference#1

Compare in Different Suspension Setup

	Front toe (deg)	Rear toe (deg)
Baseline	0.1 (toe out)	-0.1 (toe in)
Understeering bias	0.5 (toe out)	-0.5 (toe in)
Oversteering bias	-0.5 (toe in)	0.5 (toe out)



Positive number: Toe out
Negative number: Toe in

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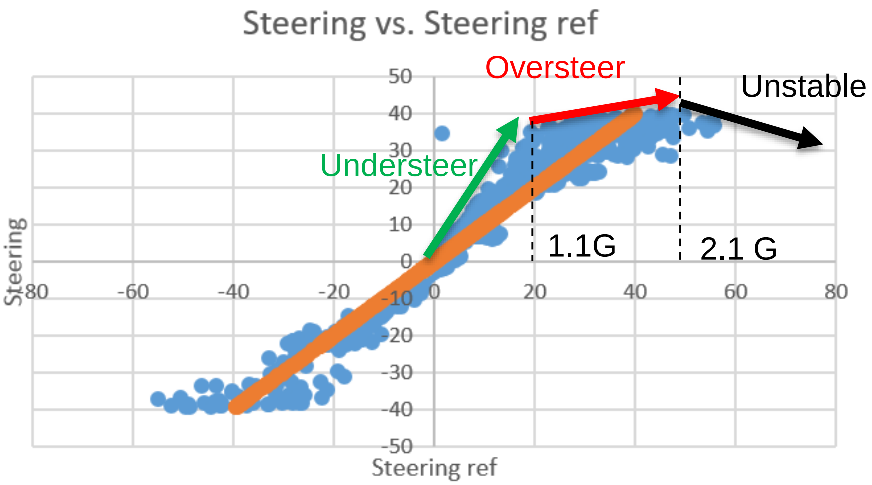
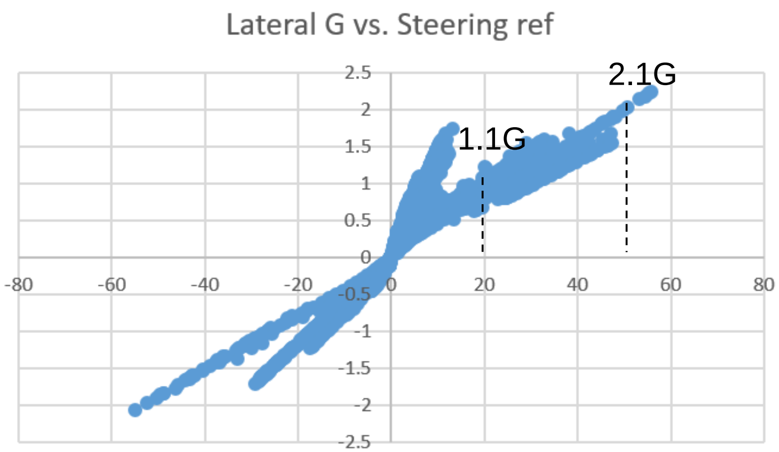
Suspension Setup - Baseline



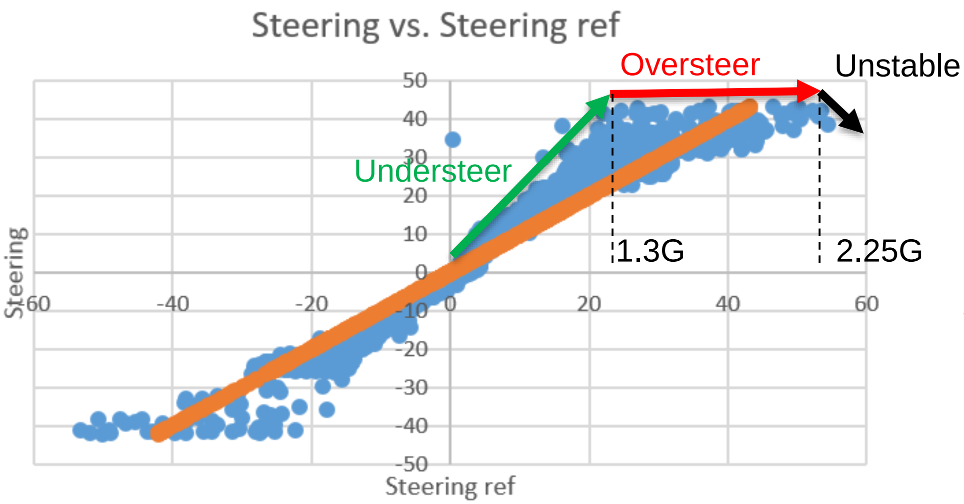


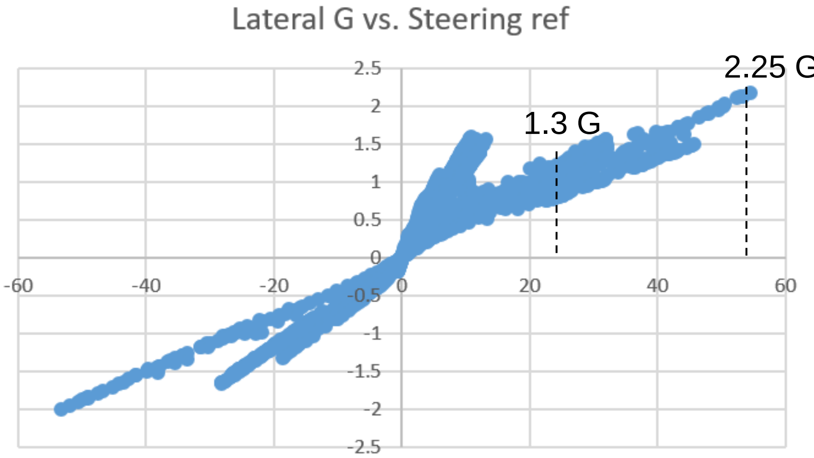
Stable margin: 2.1G

Over/Understeer transient: 1.1G

CarSim laptime estimation: 36.21 sec

Suspension Setup – Understeer bias



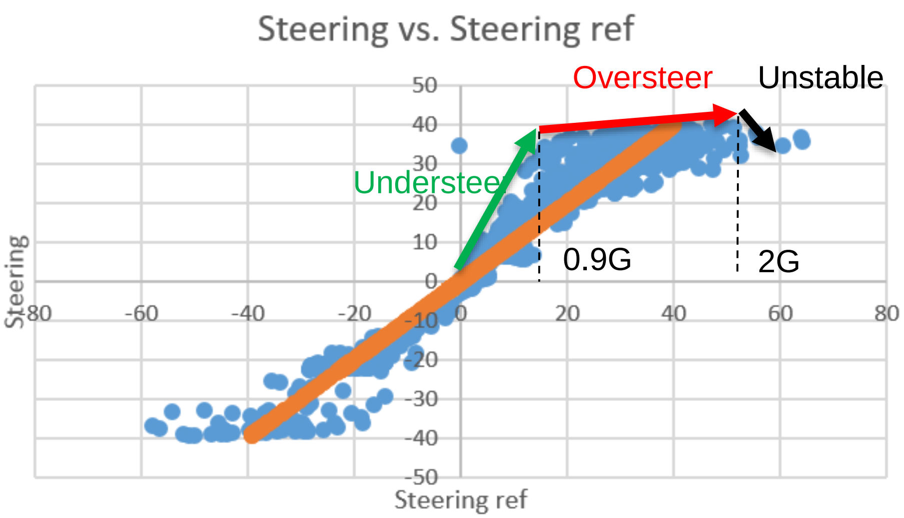


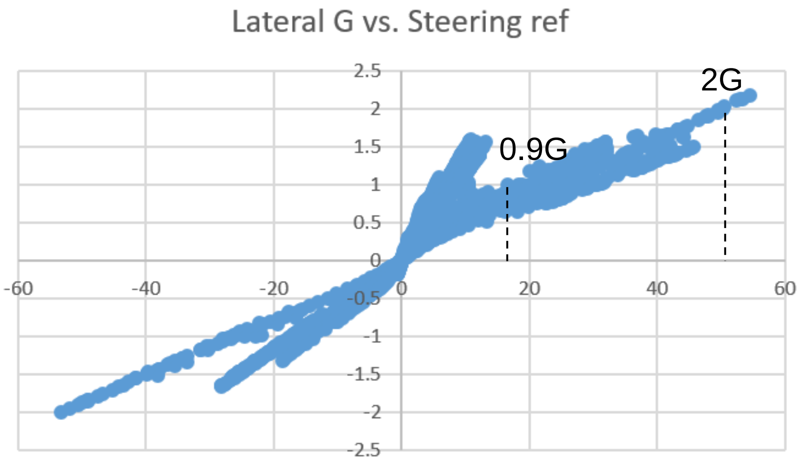
Stable margin: 2.25G

Over/Understeer transient: 1.3G

CarSim laptime estimation: 36.58 sec

Suspension Setup – Oversteer bias





Stable margin: 2.0G

Over/Understeer transient: 0.9G

CarSim laptime estimation: 36.1 sec

Camber Comparison

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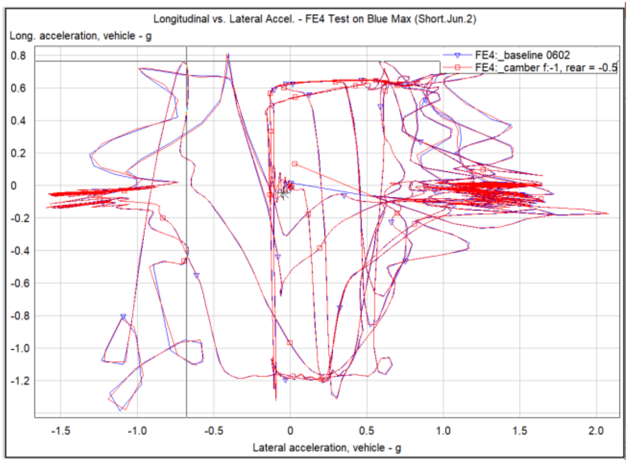
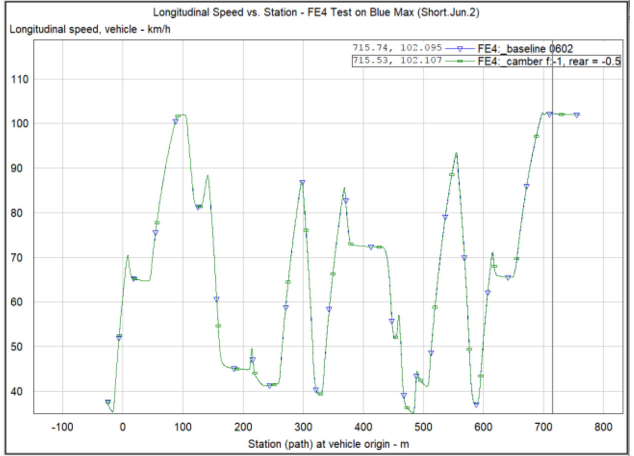
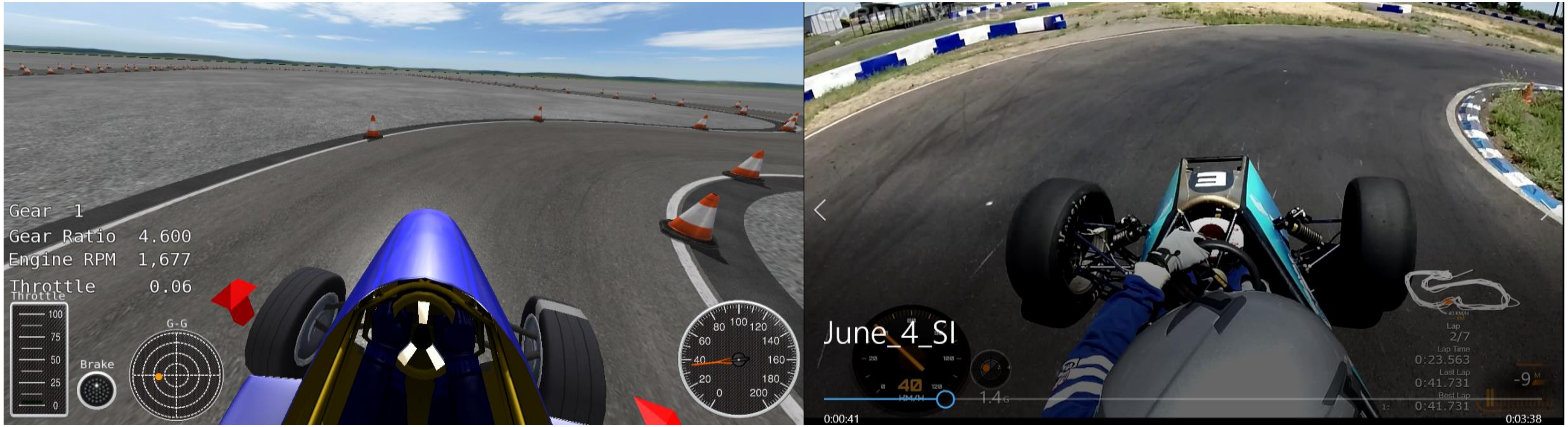
Front camber compare between (-1 and -2)





Validation of FE4

Validation of FE4



Compare CarSim (left) to real (right) at corners

Validation the Limit on Track (Baseline)

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Push to the limit (2.1G)

Spin as result (unstable)

Best lap-time in real: 36.9 sec
(baseline setting)

Validation the Limit on Track (Baseline)

	CarSim Simulation (baseline)	Real (baseline)
Best Laptime	36.21 sec	36.9 sec
Stable Margin	2.1 G	2.1 G

Validation the Limit on Track (Understeer)

	CarSim Simulation (understeer bias)	Real (understeer bias)
Best Laptime	36.58 sec	37.9 sec
Stable Margin	2.25 G	2.2 G

Validation the Limit on Track (Oversteer)

	CarSim Simulation (oversteer bias)	Real (oversteer bias)
Best Laptime	36.1 sec	38.6 sec
Stable Margin	2.0 G	1.7 G

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Conclusion

- Understeer setting make drivers feel confidence to attack corners on track, but it take longer time when entering to corners compare to baseline setting, and it result in slower lap-time.
- Oversteer setting makes drivers have much less confidence on track, and it results in much slower lap-time in real than simulation

Validation Lateral Acceleration and Speed

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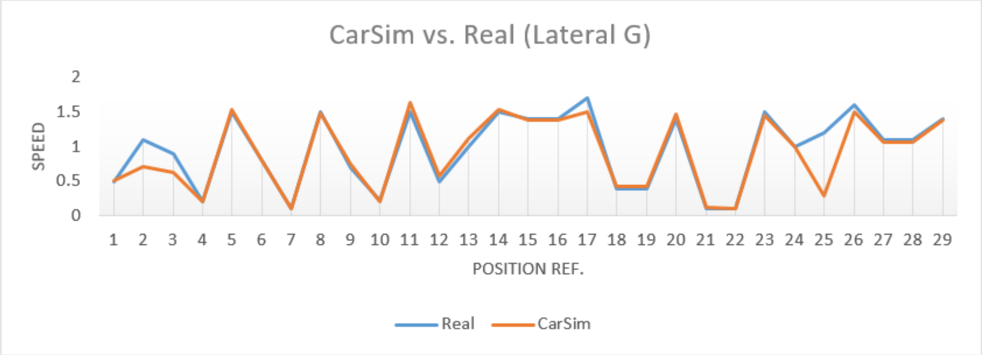
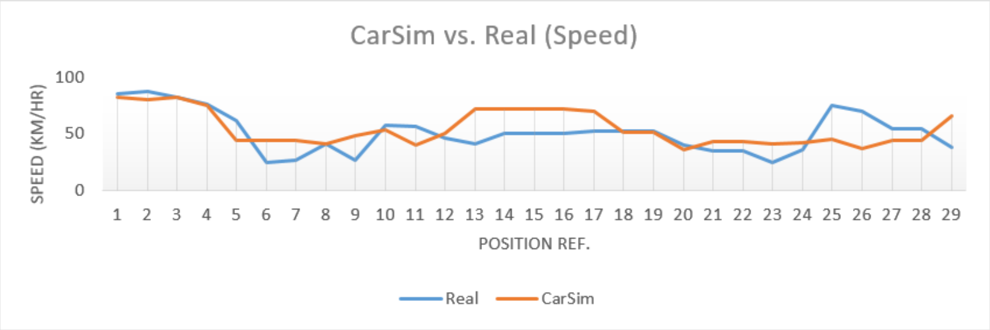
Result

- Lateral Acceleration data matched well and fit in better than FE3
- Velocity data didn't quite match as last time since the evaluation (Z-axis) profile of track didn't count in simulation
- Meanwhile, the velocity data were recorded by GPS which suffered by time delay.





Application of a Driving Simulator to Support Vehicle Design

Application of a Driving Simulator

- Using driving simulator to train driver
- Collect data from simulator during training
- Base on the best lap-time and driving feel, record the data
- Convert the data to transfer functions (ex: $\frac{\boldsymbol{Yaw\ rate}}{\boldsymbol{Steer\ angle}}$)
- Tune the parameters of vehicle dynamic model to meet the required transfer functions
- Base on the estimate parameters to help design the car

Procedure

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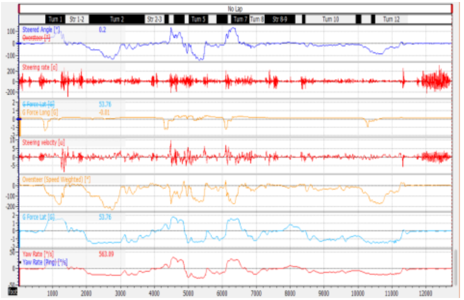
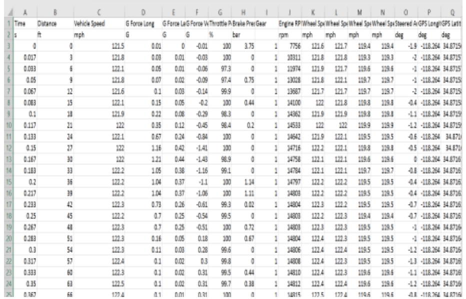
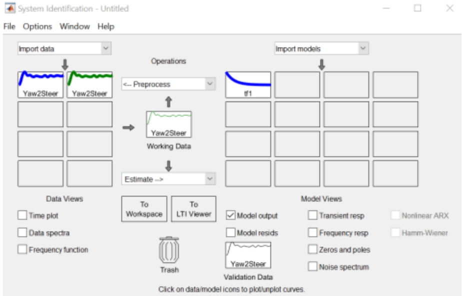
1, Simulator application



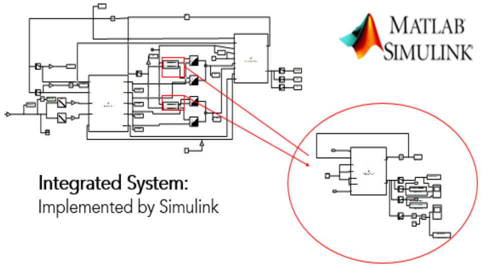
2, Using Motec to collect data from simulator



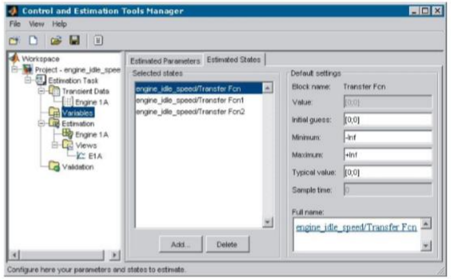
3, Export data to Excel



4, Convert to transfer functions



5, Vehicle dynamic model application



6, Estimate parameters to meet the required transfer functions

Case Study

Is it possible to design FE4 and make it drive like a Tesla Model S or Formula 3?

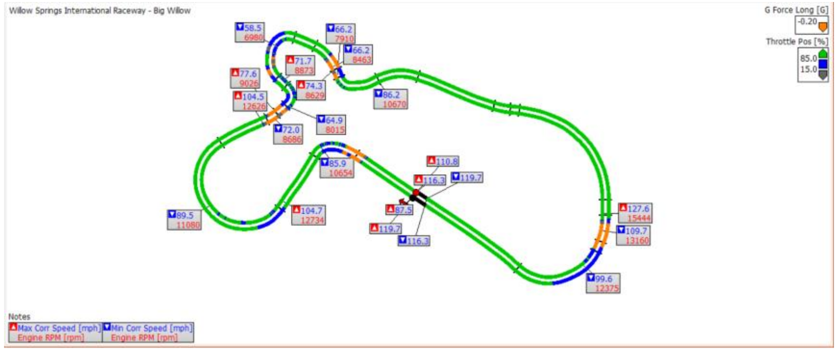
FE4

Tesla Model S

F3 - Ayrton Senna West Surrey Racing ’85

Collect Data from Simulator by Motec

- **Test track**: Willow Springs
- **Test cars**: Model S and F3
- **Software of Simulator**: Gran Turismo 6



Convert Data to Transfer Function – Model S

Transfer function: $\frac{Yaw\ rate}{Steer\ angle} = \frac{r}{\delta}$

Rise time: 2.17 sec

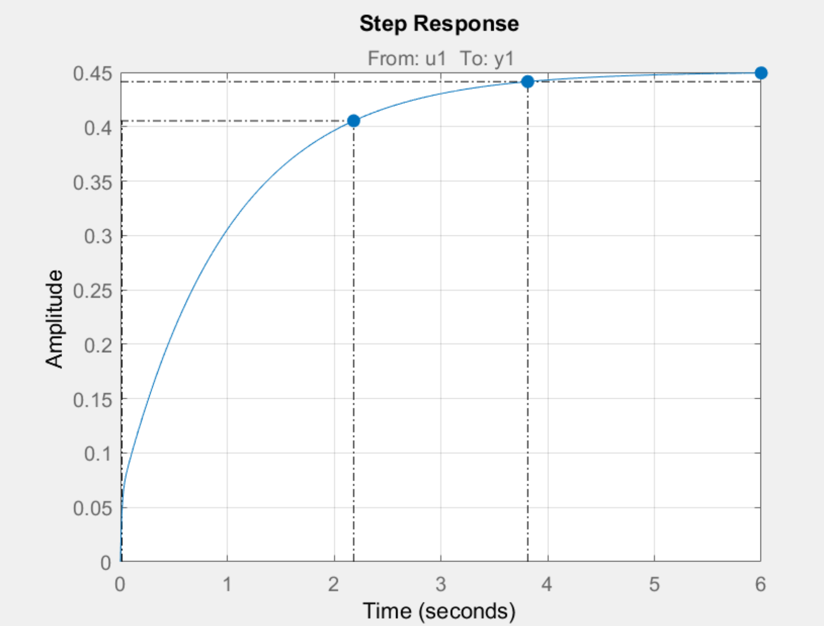
Settling time: 3.81 sec

Overshoot: 0 %

Static gain: 0.45

```
Model_S =
Process model with transfer function:
                   1+Tz*s
  G(s) = Kp * ------------------ * exp(-Td*s)
              (1+Tp1*s)(1+Tp2*s)

         Kp = 0.45045
        Tp1 = 1.0127
        Tp2 = 0.012982
         Td = 0
         Tz = 0.14881
```



Step response – Model S

Convert Data to Transfer Function – F3

Transfer function: $\dfrac{\textit{Yaw rate}}{\textit{Steer angle}} = \dfrac{r}{\delta}$

Rise time: 0.115 sec

Settling time: 0.275 sec

Static gain: 0.348

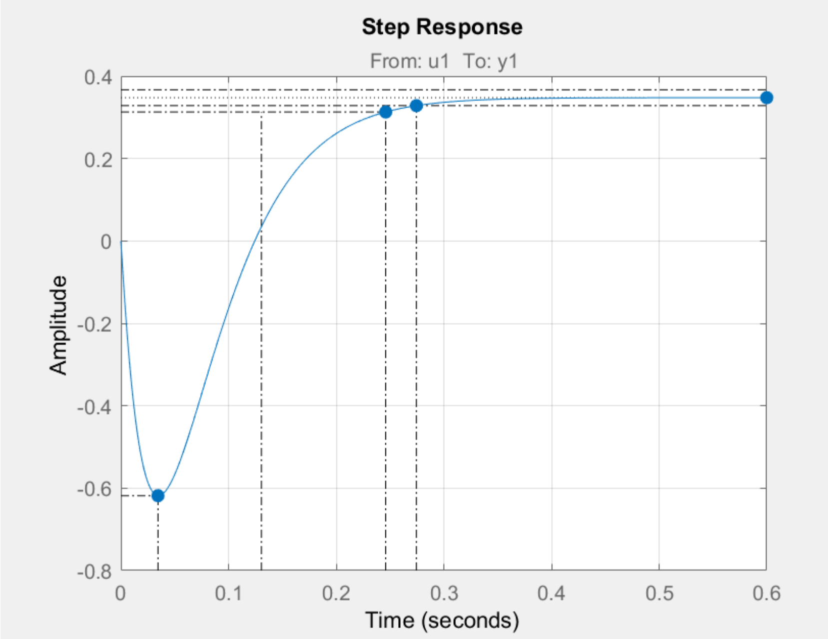
Reverse peak amplitude: -0.6

Duration of reverse response: 0.034 sec

```
F3 =
Process model with transfer function:
                   1+Tz*s
  G(s) = Kp * ------------------ * exp(-Td*s)
              (1+Tp1*s)(1+Tp2*s)

        Kp = 0.34765
       Tp1 = 0.041541
       Tp2 = 0.040624
        Td = 0.000136
        Tz = -0.22479
```

There is an unstable zero which cause reverse response



Step response – F3

Convert Data to Transfer Function – FE4

Transfer function: $\frac{Yaw\ rate}{Steer\ angle} = \frac{r}{\delta}$

Rise time: 0.079 sec

Settling time: 0.118 sec

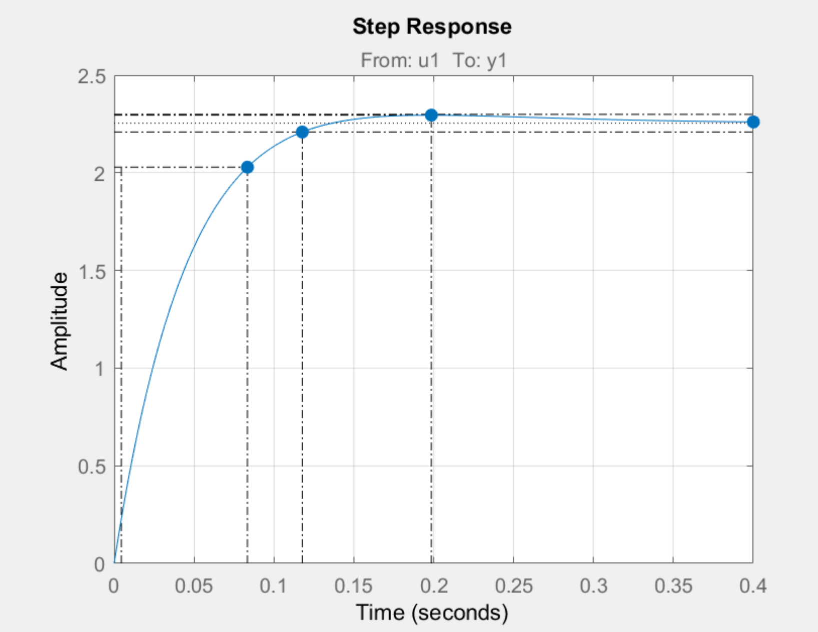
Peak time: 0.199 sec

Overshoot: 1.83 %

Static gain: 2.25

```
FE4 =
Process model with transfer function:
                   1+Tz*s
  G(s) = Kp * ------------------ * exp(-Td*s)
              (1+Tp1*s)(1+Tp2*s)

        Kp = 2.2539
       Tp1 = 0.062479
       Tp2 = 0.060785
        Td = 0
        Tz = 0.089527
```



Step response – FE4

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Comparison

	Model S	F3	FE4
Rise time	2.17	0.115	0.079
Settling time	3.81	0.275	0.118
Static gain	0.45	0.348	2.25
Reverse response?	No	Yes	No

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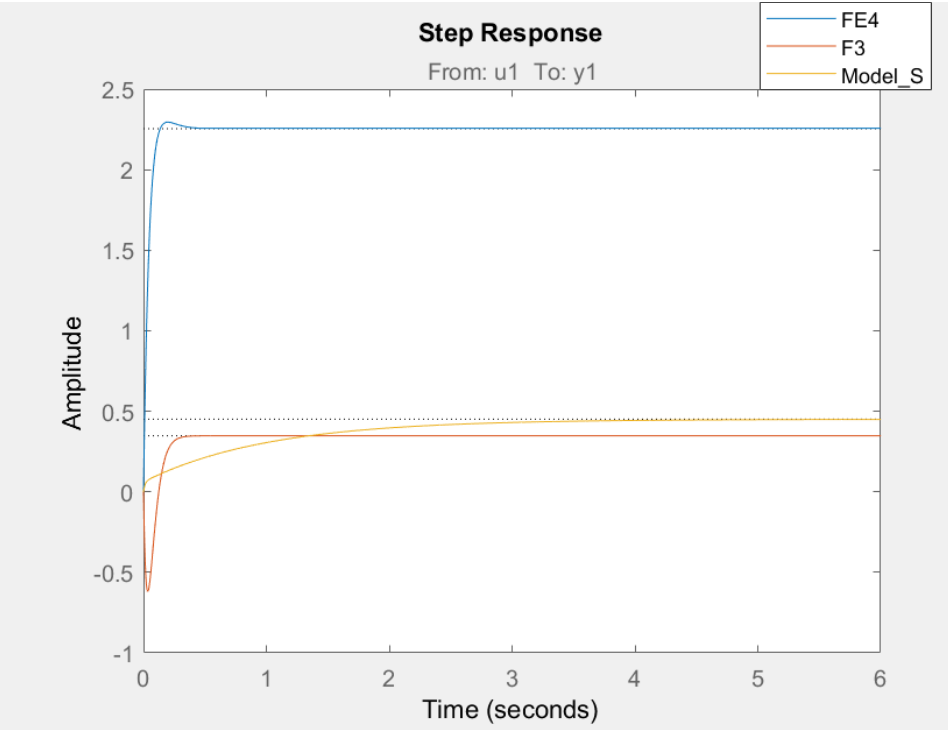
Comparison

From the information, FE4 has the fastest response, but the static gain is too high which will make the steering feel too sensitive.

Therefore, it suggests using higher steering rack ratio to decrease the static gain and make it closed to Formula 3 which our drivers preferred.



Goal of Future

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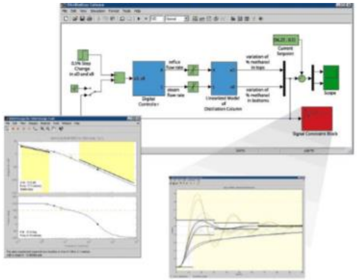
After collecting the transfer functions, using the *Simulink Parameter Estimations* to tune the parameters of vehicle dynamic model (ex: rear suspension spring coefficient or damping coefficient) to help design the car.

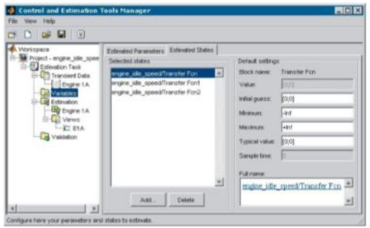
Simulink Response Optimization

- Optimize system behavior by tuning design parameters



Simulink Parameter Estimation

- Estimate model parameters using test data



Limitation

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- Some physical parameters (ex: mass or moment of inertia) are hard to tune
- The data are based on the simulator (Gran Turismo in the case), not real cars; therefore, data might be off from real.
- Transfer function is linear, but in real live it's nonlinear, so it would be hard to make the dynamic response of the car on design stage (like FE4) 100% match to the model car (like Formula 3).
- The transfer functions vary depend on the test conditions. (ex: tracks, weather, road condition…etc)

Reference

1. Karnopp, Dean. *Vehicle Dynamics, Stability, and Control.* Boca Raton, FL: CRC, 2013. Print.
2. Segers, JoÌrge. *Analysis Techniques for Racecar Data Acquisition*. Warrendale, PA: SAE International, 2014. Print.
3. "Introduction to the International Roughness Index." (n.d.): n. pag. Minnesota Department of Transportation, 11 Apr. 2007. Web. 14 June 2017.

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Questions


Thank You !
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