Formula 1

Banned Technology

CAE CHAMPION

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FRICS

2

Full-Car Model

3

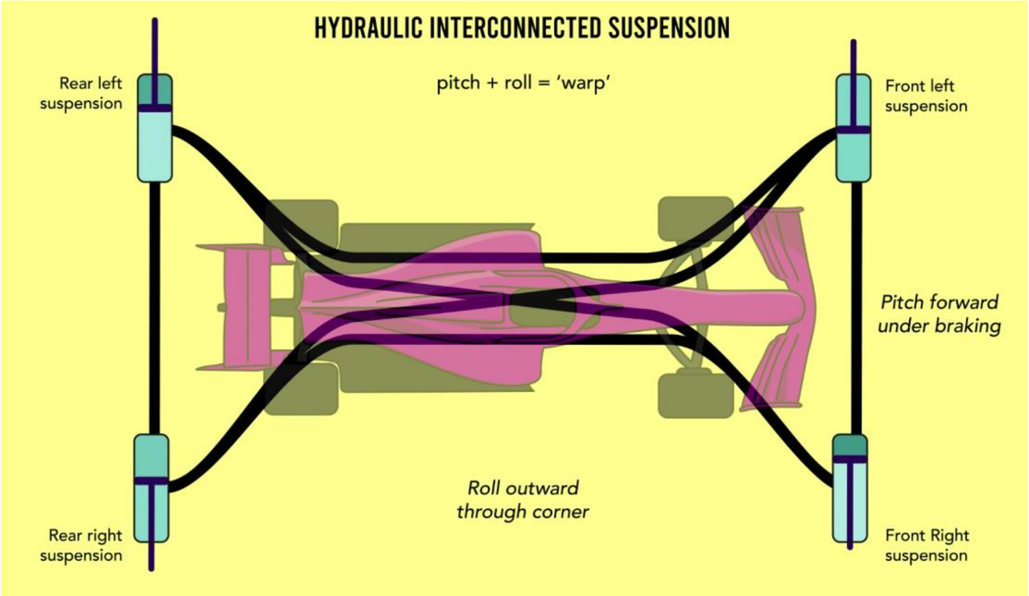
Mass-Damper

4

AeroDynamics

5

Difficulties & Reflections

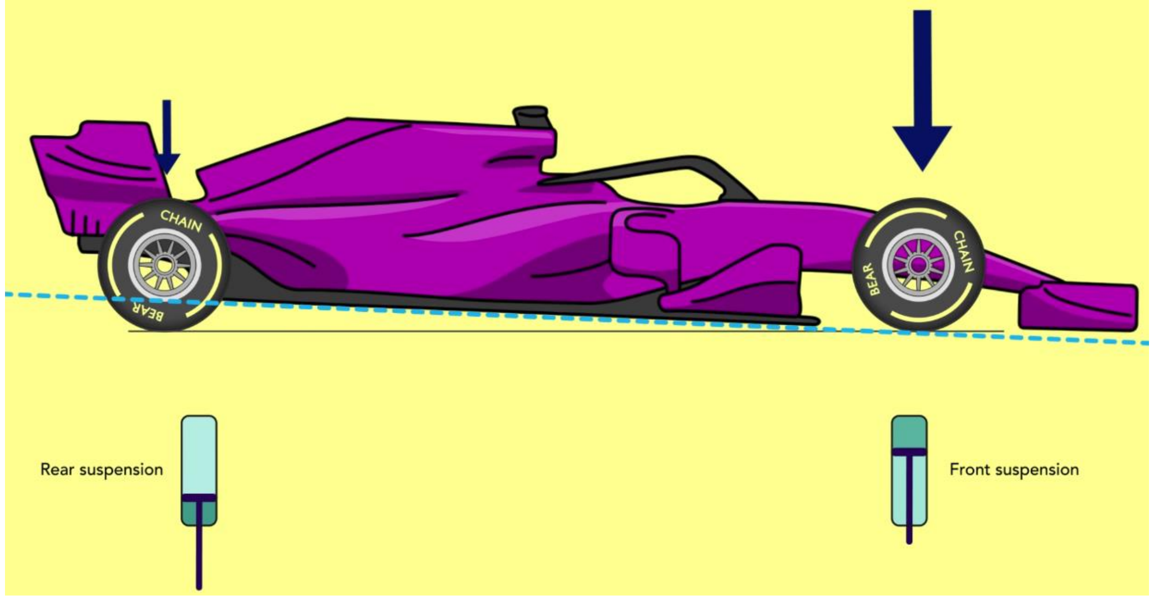


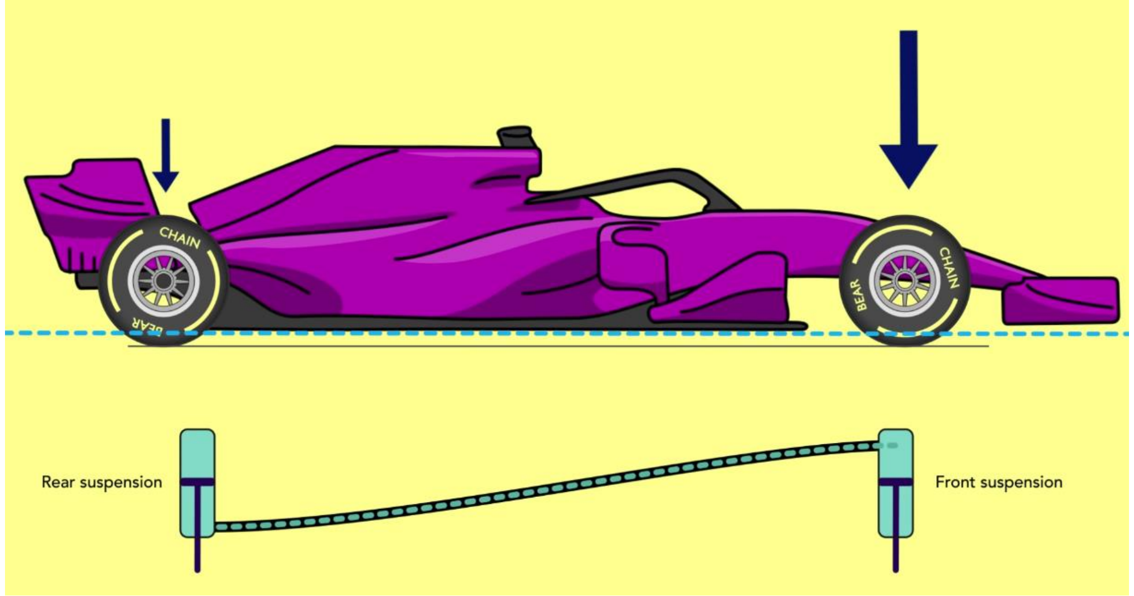
1

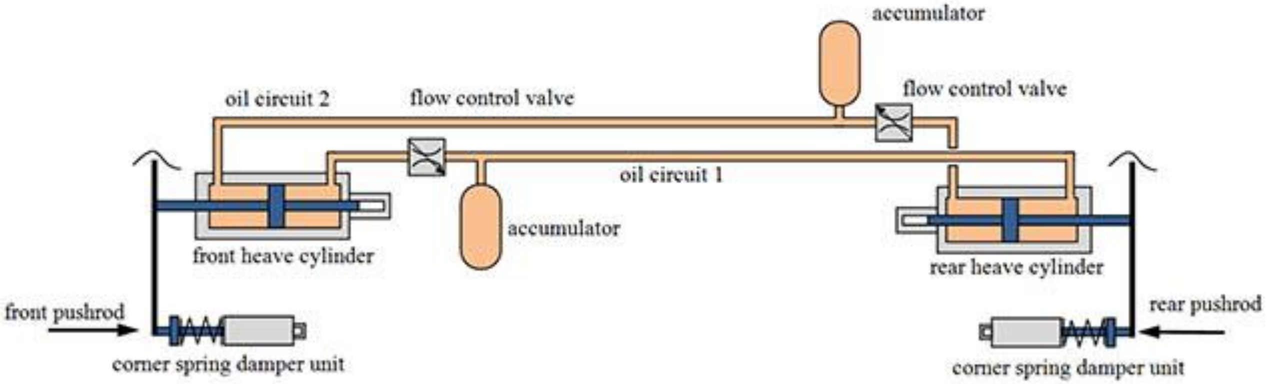
FRICS

Front and Rear InterConnected Suspension

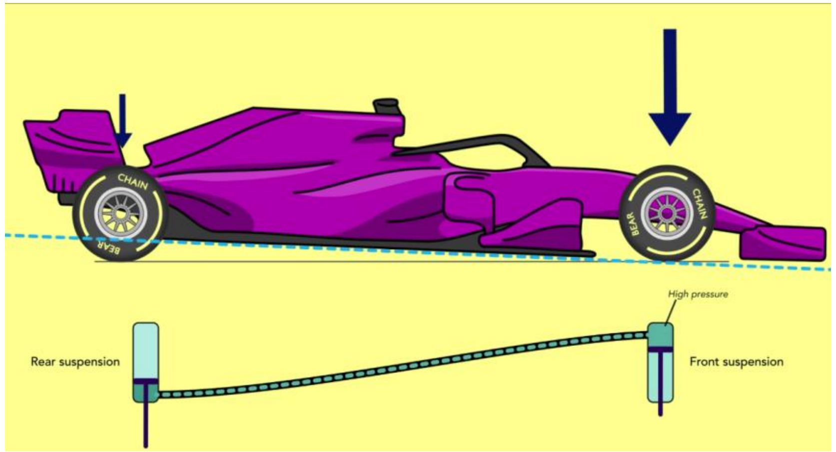
1 FRICS : Front and Rear Interconnected Suspension

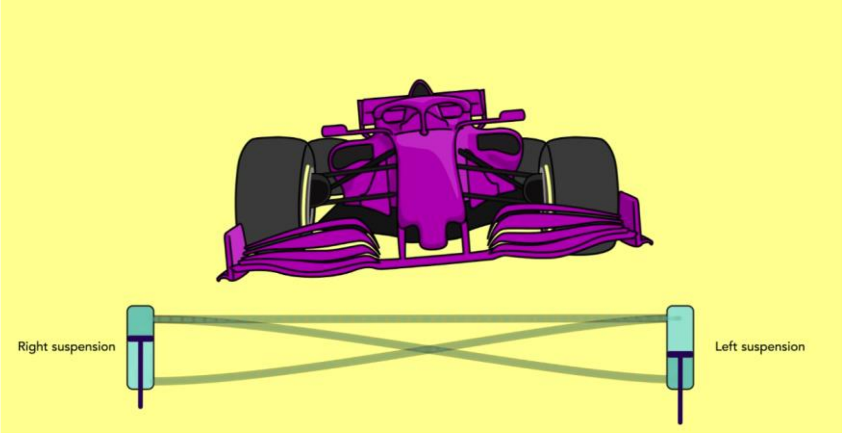


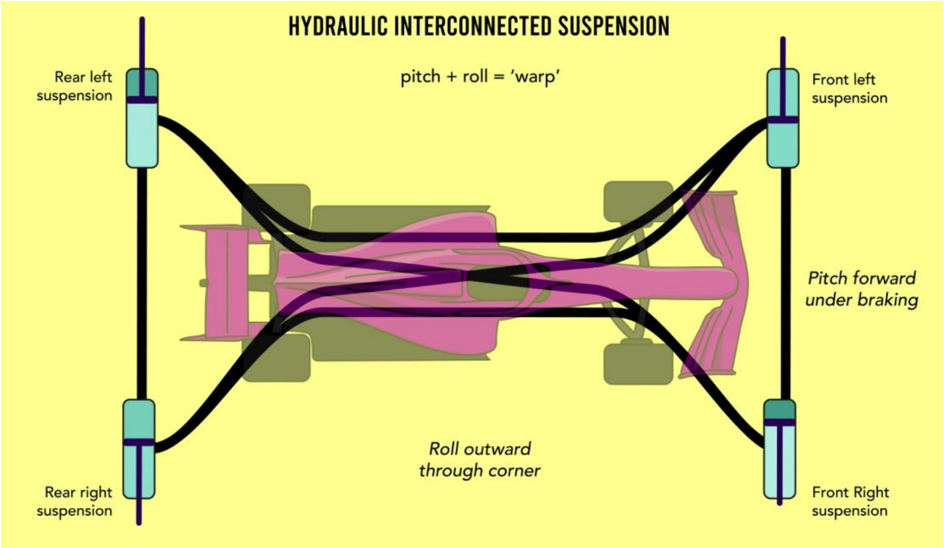




1 FRICS : Front and Rear Interconnected Suspension



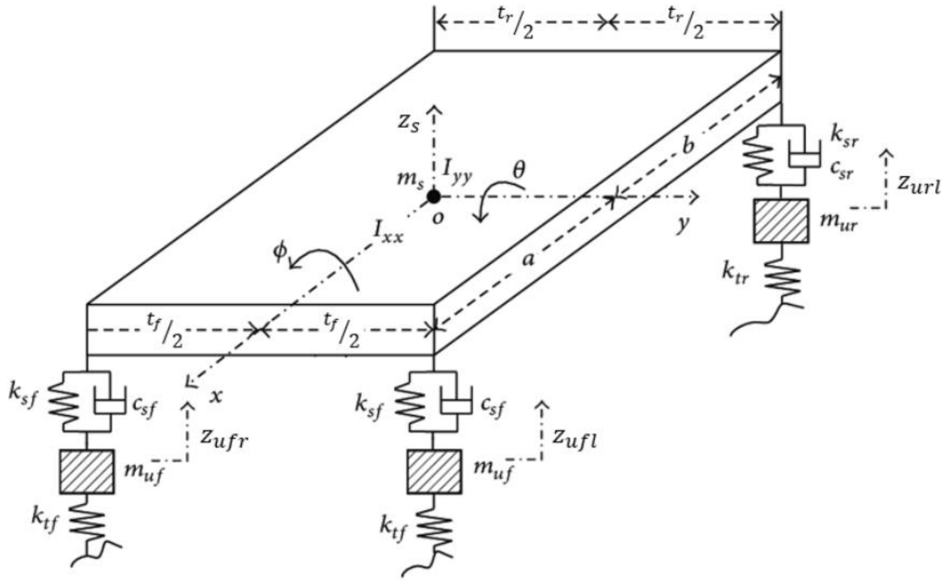




전방과 후방 서스펜션의 움직임을 상호 연계

주행 중 차량의 자세, 각도의 흔들림을 최소화, 균형 있게 유지

→ **Downforce, Dragforce**를 일정하게 유지, 고속에서의 안정성 향상

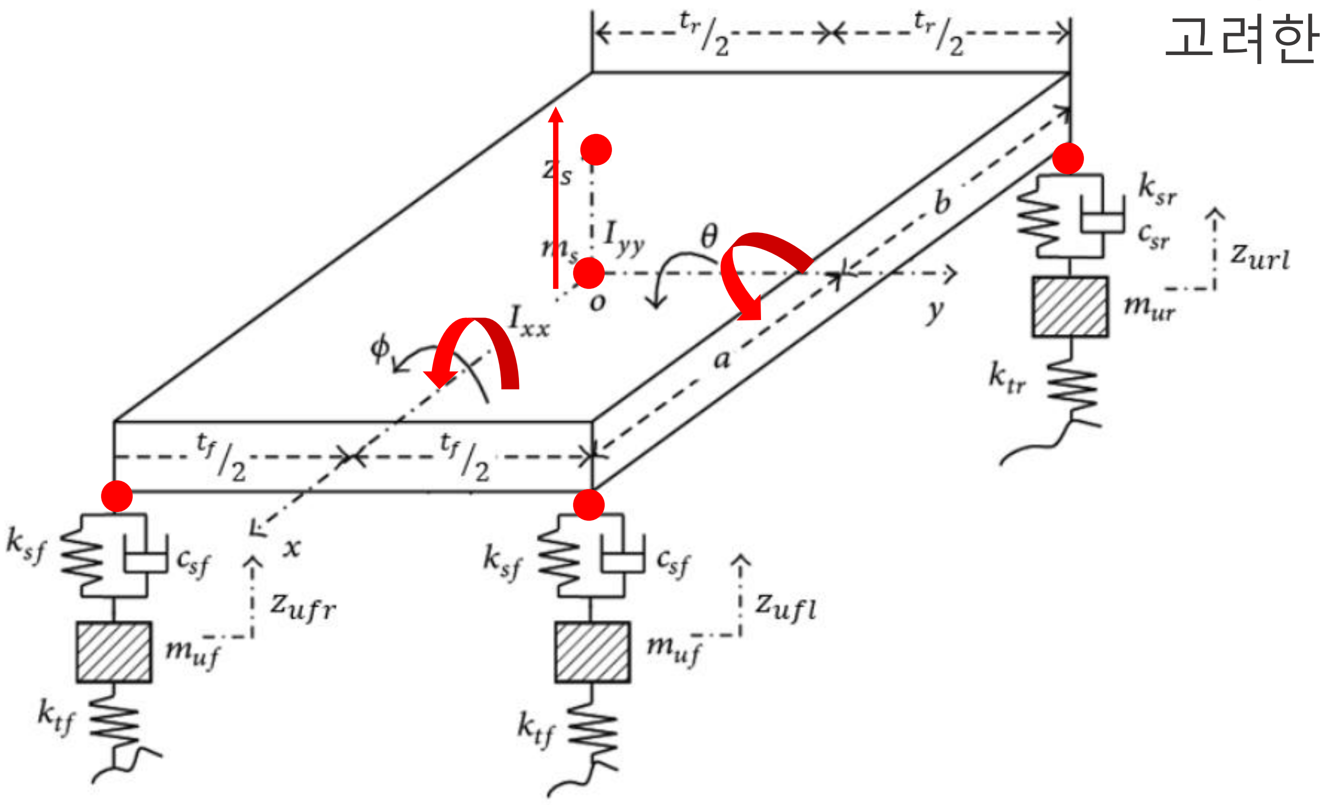


2

Full – Car Model

2 Full – Car Model

FRICS를 설치할 기본 모델 및 대조군의 역할을 위해
Full – Car Model 작성



고려한 지점 : 각 서스펜션 시스템 4군데, 가운데 무게중심
고려한 position : Z변위, Pitch, Yaw

지면 변위 4개
$(z_{ground,FR}, z_{ground,FL}, z_{ground,RR}, z_{ground,RL})$

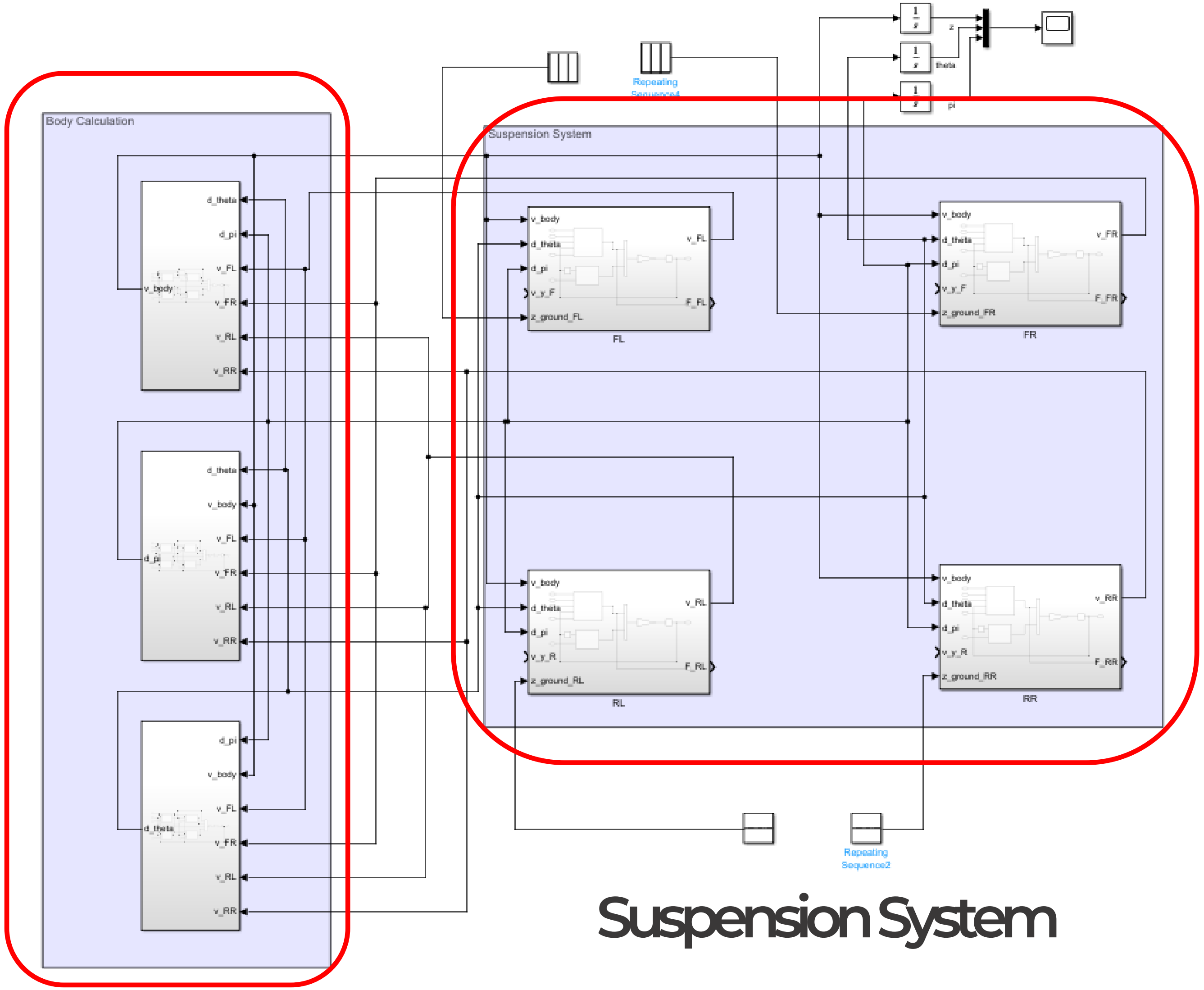
서스펜션(unsprung) 변위 4개
$(z_{FR}, z_{FL}, z_{RR}, z_{RL})$

차량(sprung)에 대한 움직임 3개
$(z, \theta, \emptyset)$

차량의 길이, 질량 등의 정보 10개
$(w, L_F, L_R, m_{vehicle}, I_{xx}, I_{yy})$
$(m_{FR}, m_{FL}, m_{RR}, m_{RL})$

서스펜션에 대한 계수 8개
$(k_{FR}, k_{FL}, k_{RL}, k_{LR}, c_{FR}, c_{FL}, c_{RL}, c_{LR})$

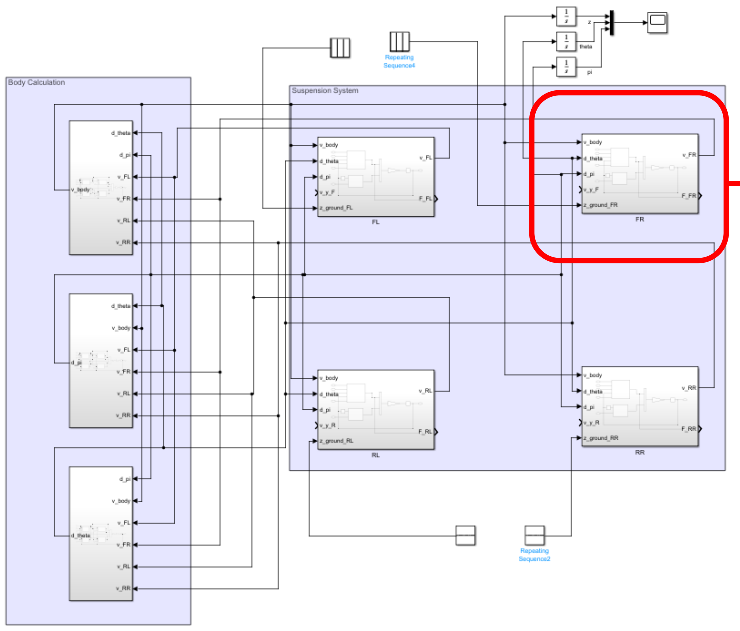
2 Full – Car Model



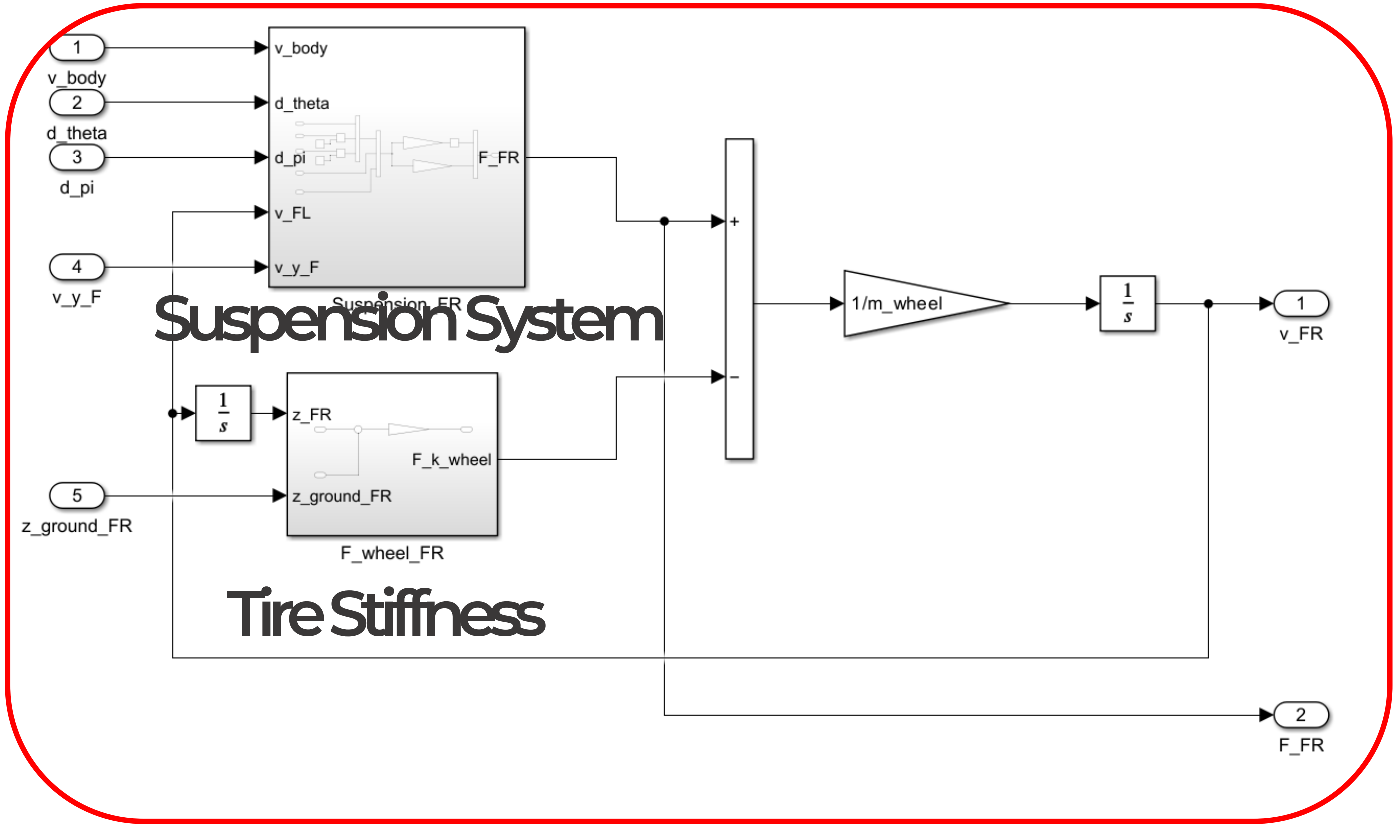
Body Calculation

Suspension System

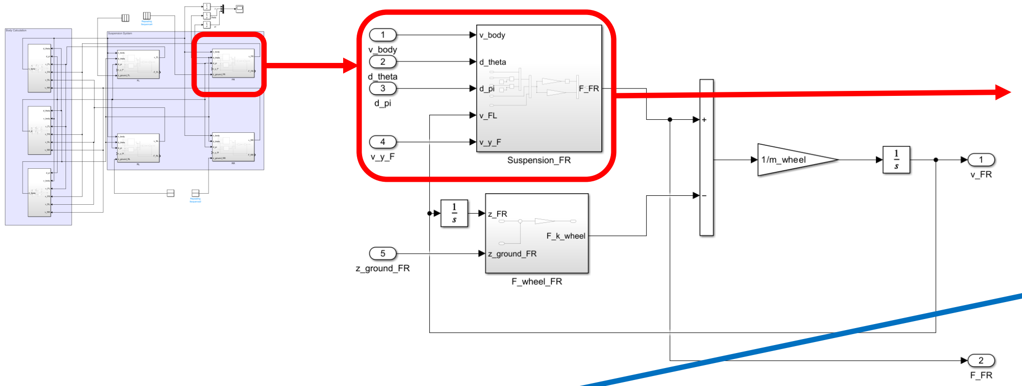
2 Full – Car Model



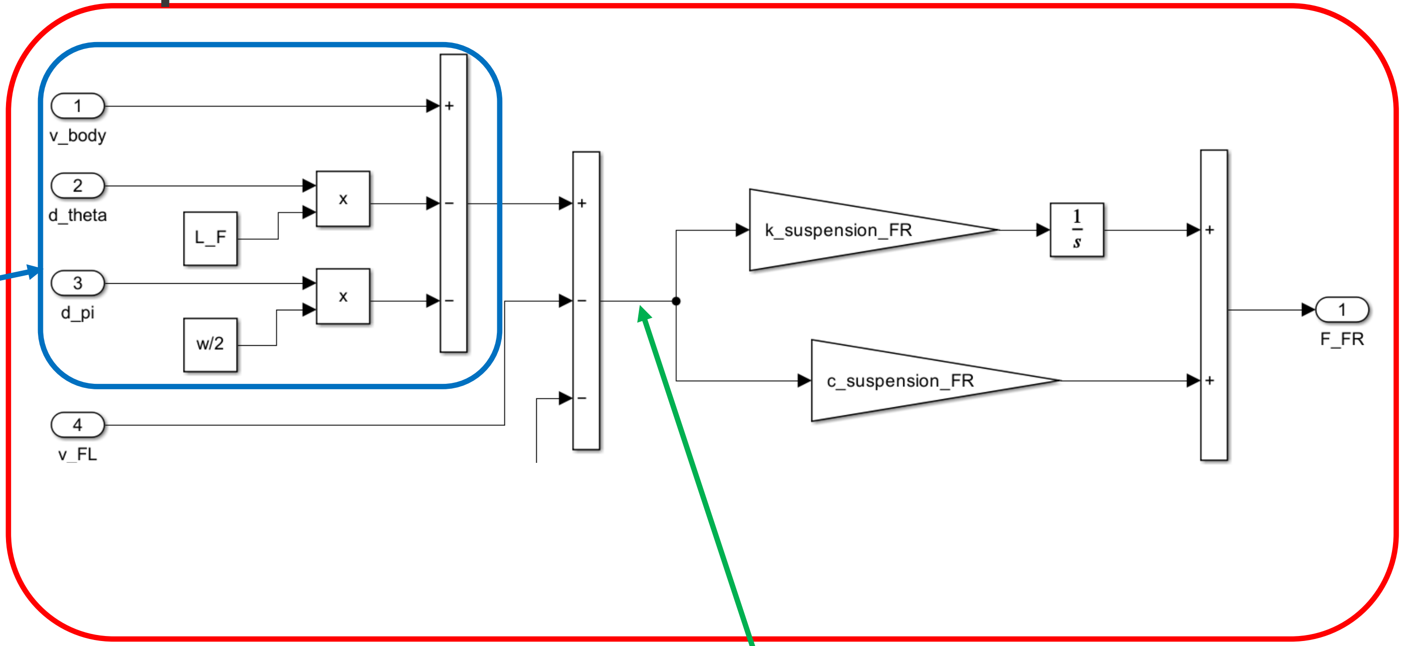
FR (Front, Right) : 오른쪽 앞바퀴와 연결된 Suspension System



2 Full – Car Model

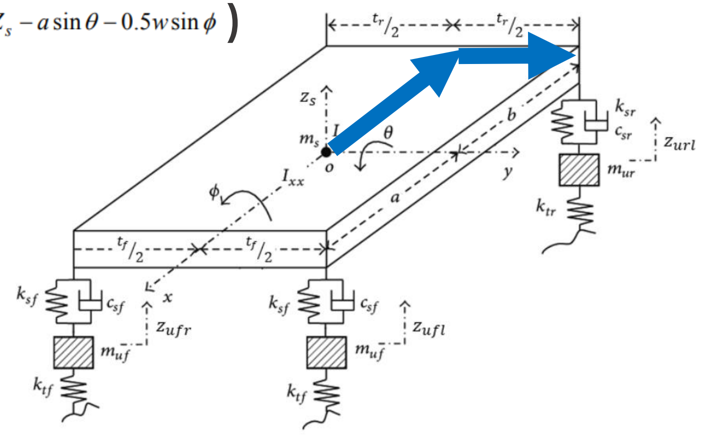


Suspension_FR



$$Z_{s,fr} = Z_s - a\theta - 0.5w\phi$$

$$(\ Z_{s,fr} = Z_s - a\sin\theta - 0.5w\sin\phi\ )$$

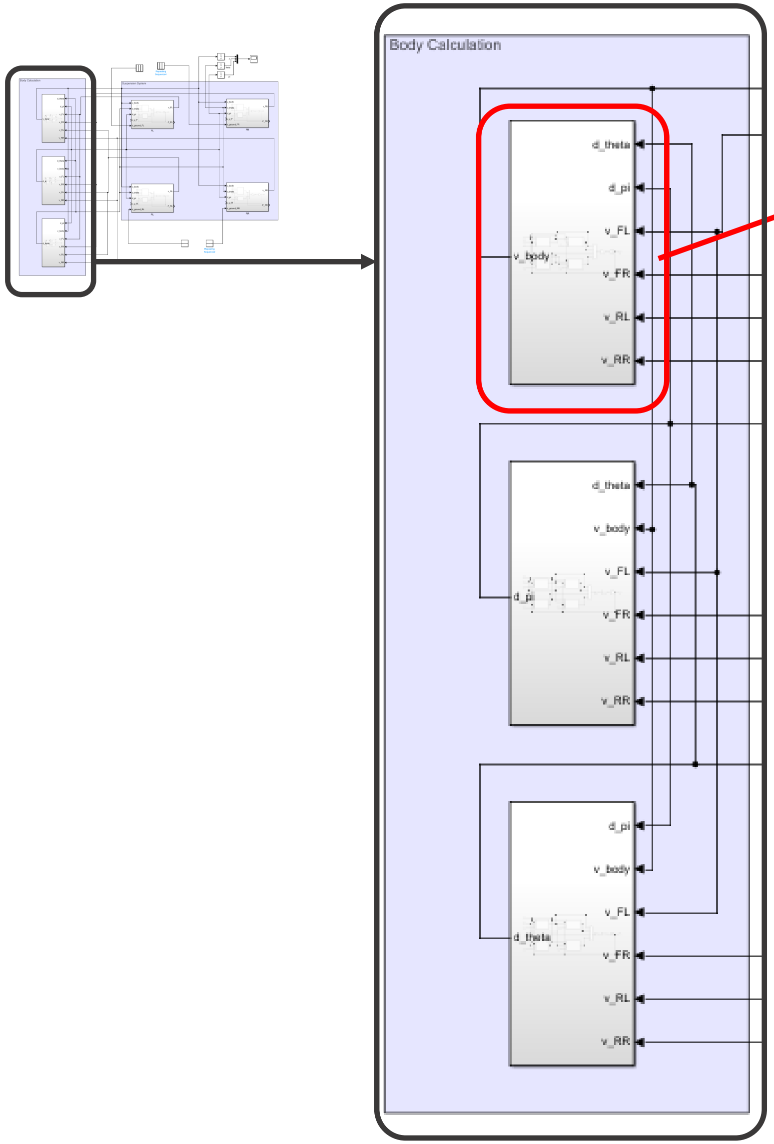


$$F_{fr} = K_{s,fr}\left(Z_{u,fr} - Z_{s,fr}\right) + C_{s,fr}\left(\dot{Z}_{u,fr} - \dot{Z}_{s,fr}\right)$$

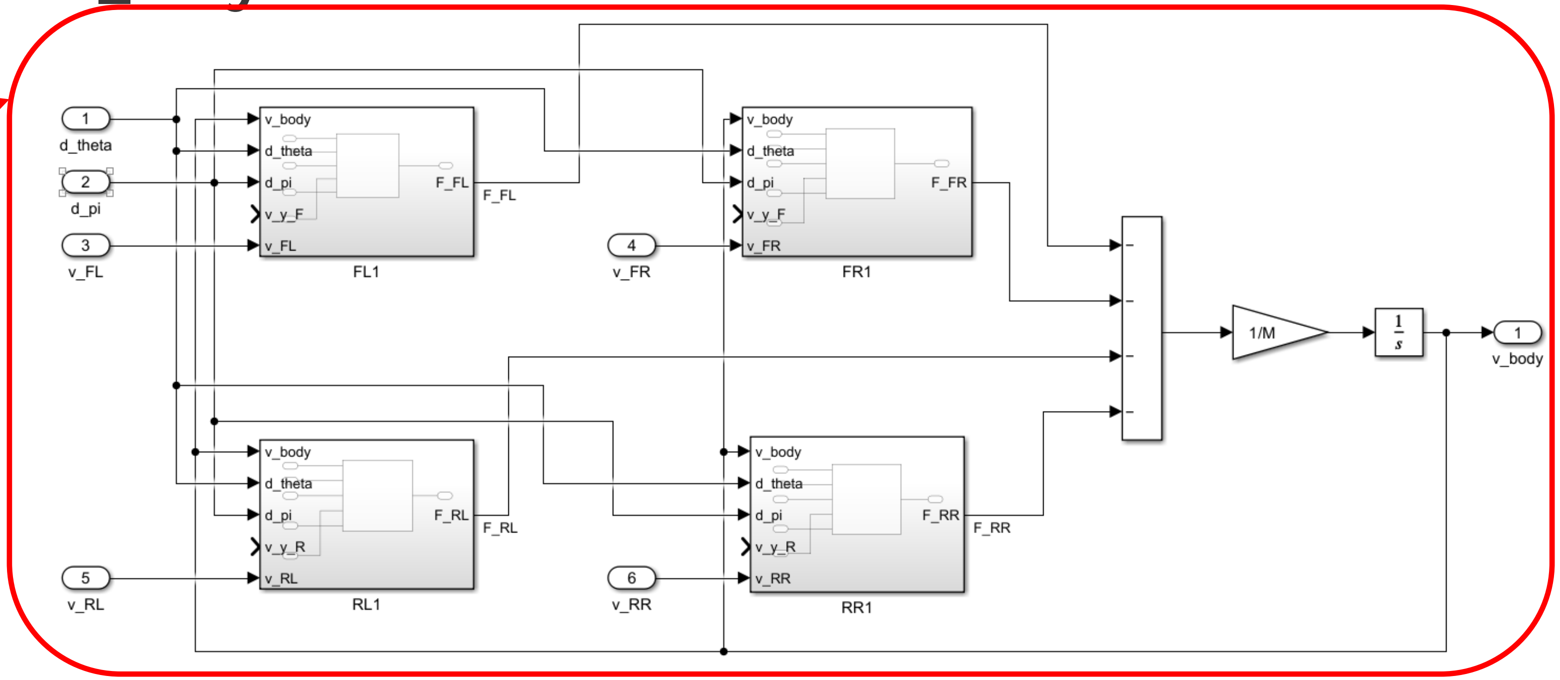
변위(속도)를 기반으로 **spring, damper**의 힘 계산

FR지점의 변위(속도)를 차량 무게중심의 변위 기반으로
Pitch(Φ), Yaw(Φ)와 차량의 크기를 고려하여 계산

Full – Car Model



v_body calculation

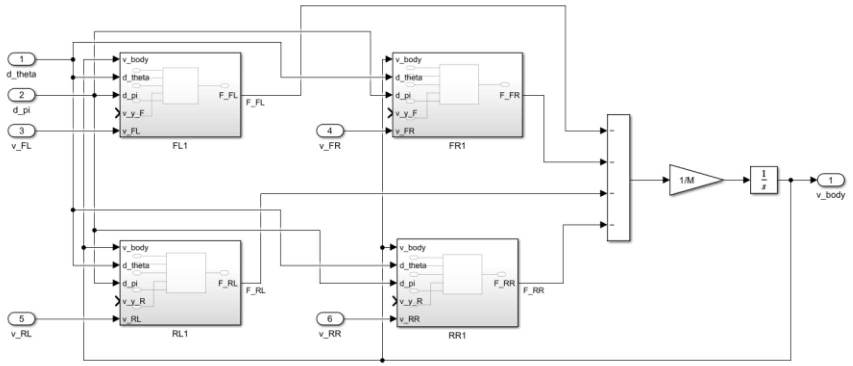


Body의 **position** 계산하는 **area.**
각 **subsystem** 내부는 대부분 위와 같은 형태로 구성되어 있음.

Q) 왜 외부의 서스펜션 **(FL, FR, RL, RR)**값을 그대로 사용하지 않았는가?
왜 세 개의 **subsystem**으로 따로 구현했는가?

2 Full – Car Model

Q) 왜 외부의 서스펜션 (FL, FR, RL, RR)값을 그대로 사용하지 않았는가? 왜 세 개의 subsystem으로 따로 구현했는가?



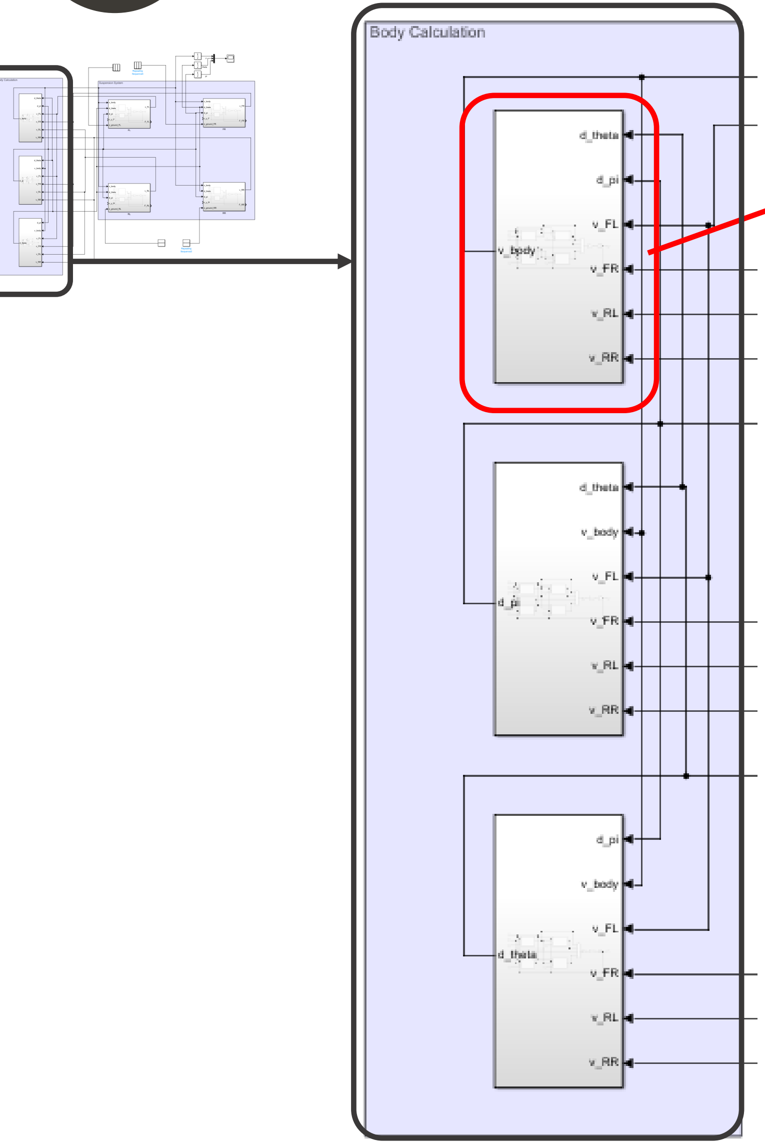
3. 대수 루프 주의 사항

입력과 출력에 동일한 변수를 사용할 때는 **대수 루프**가 발생할 가능성이 큽니다. 대수 루프는 다음과 같은 문제를 일으킬 수 있습니다:

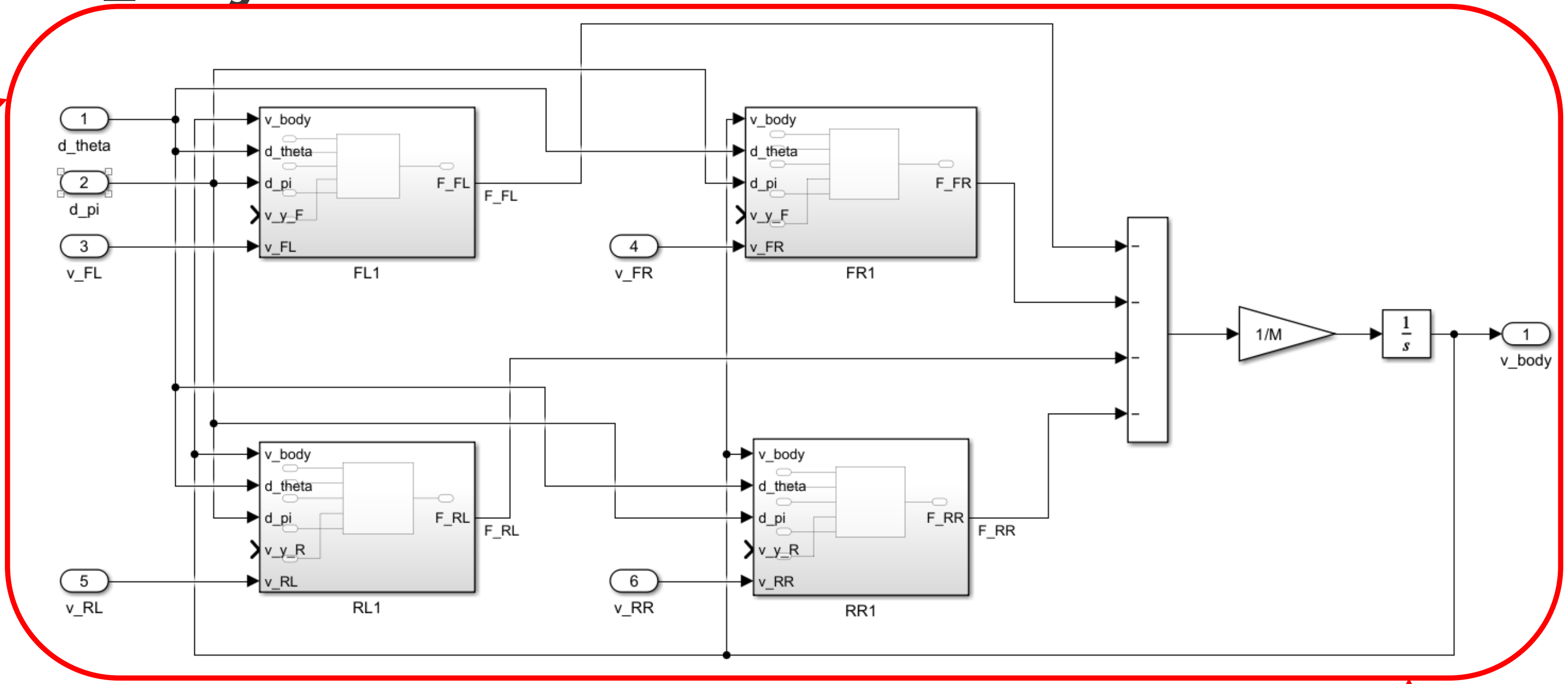
- 시스템의 상태나 변수가 **순환적인 의존성**을 가질 때, Simulink는 이를 해결할 방법을 찾지 못할 수 있습니다.
- 대수 루프를 해결하기 위해 Simulink는 특정 해결 방법을 사용하지만, 때때로 **수치적으로 불안정**할 수 있고, 이로 인해 **시뮬레이션이 제대로 실행되지 않을 수 있습니다**.

한 Subsystem의 output 값을 그대로 다시 input으로 사용한다면 (input에 있는 변수를 output으로도 출력한다면) 순환적인 의존성으로 인해 수치적 불안정

2 Full – Car Model

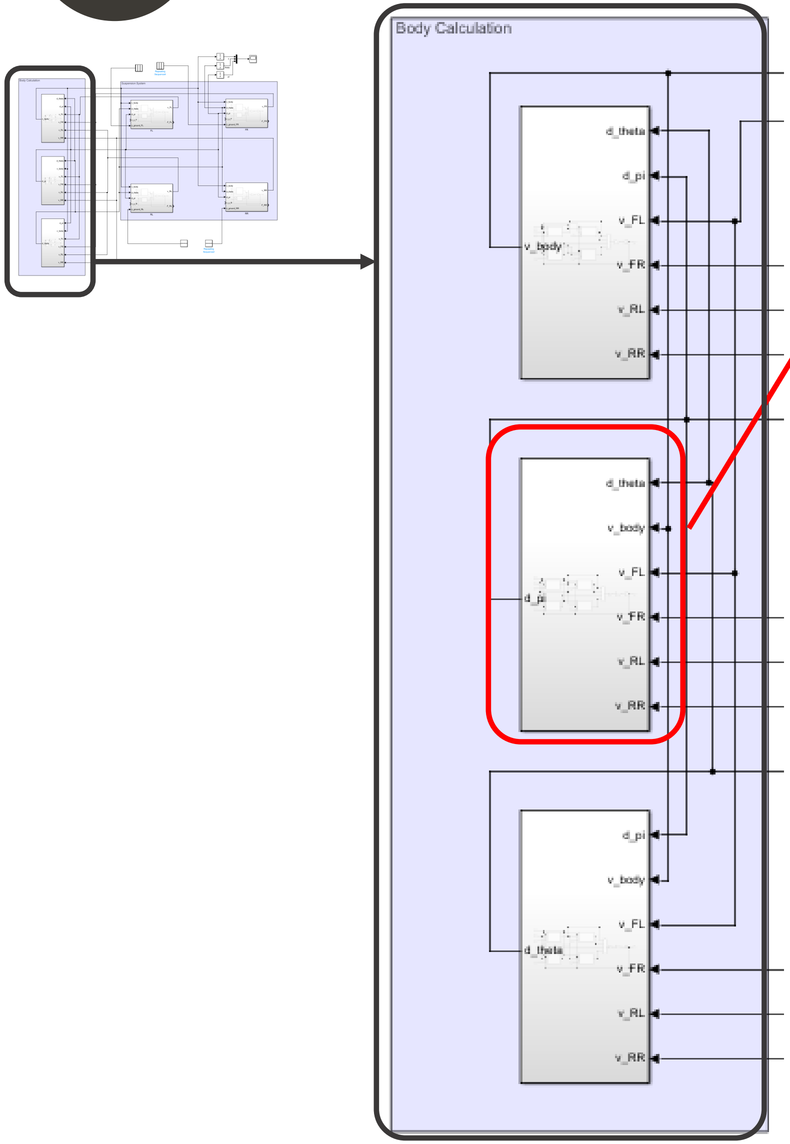


v_body calculation

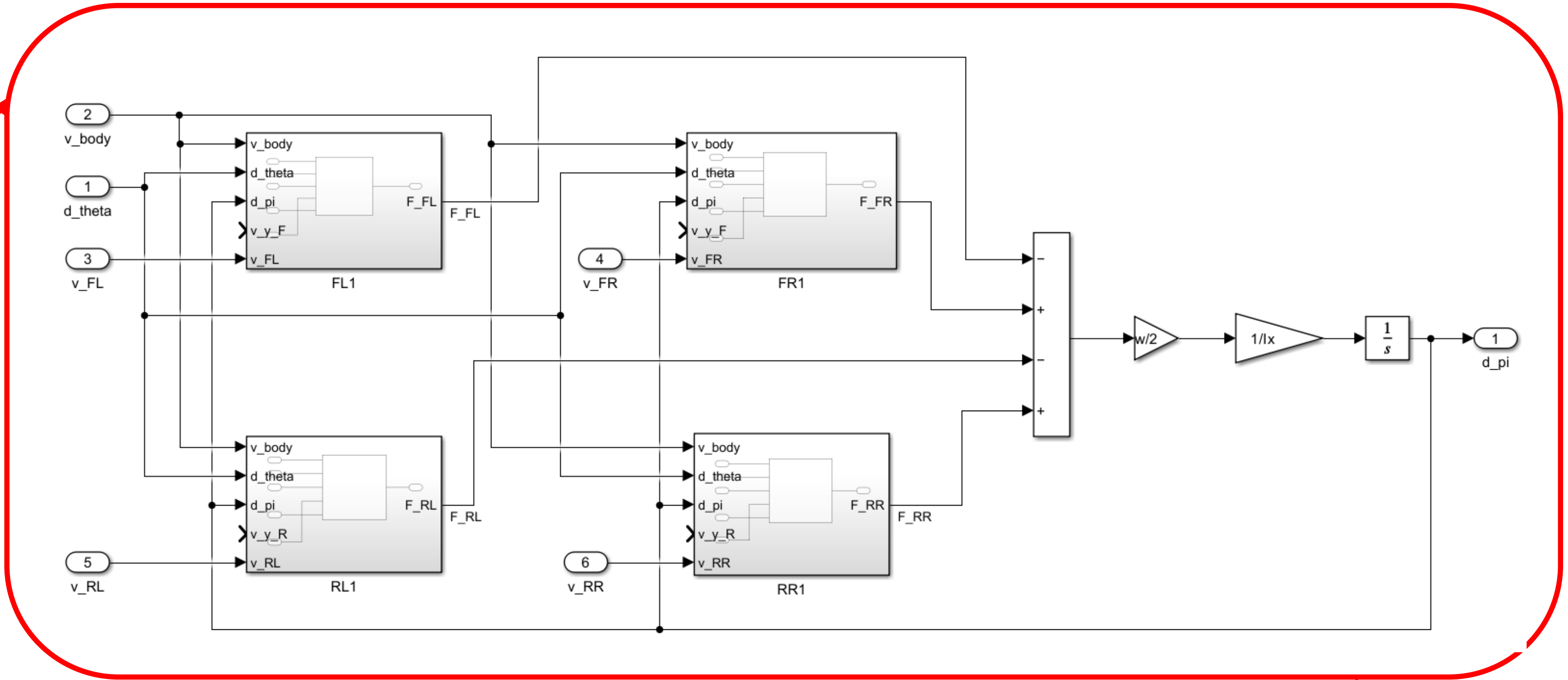


$$
\begin{aligned}
m_s \ddot{Z}_s = & -2\left(K_{s,f} + K_{s,r}\right) Z_s - 2\left(C_{s,f} + C_{s,r}\right)\dot{Z}_s + 2\left(aK_{s,f} - bC_{s,r}\right)\theta \\
& + \ 2\left(aC_{s,f} - bC_{s,r}\right)\dot{\theta} + K_{sf} Z_{u,fl} + C_{s,f}\dot{Z}_{u,fl} + K_{sf} Z_{u,fr} \\
& + \ C_{s,f}\dot{Z}_{u,fr} K_{sr} Z_{u,rl} + C_{s,r}\dot{Z}_{u,rl} + K_{sr} Z_{u,rr} + C_{s,r}\dot{Z}_{u,rr} \\
& + \ F_{pfl} + F_{pfr} + F_{prl} + F_{prr}
\end{aligned}
$$

2 Full – Car Model

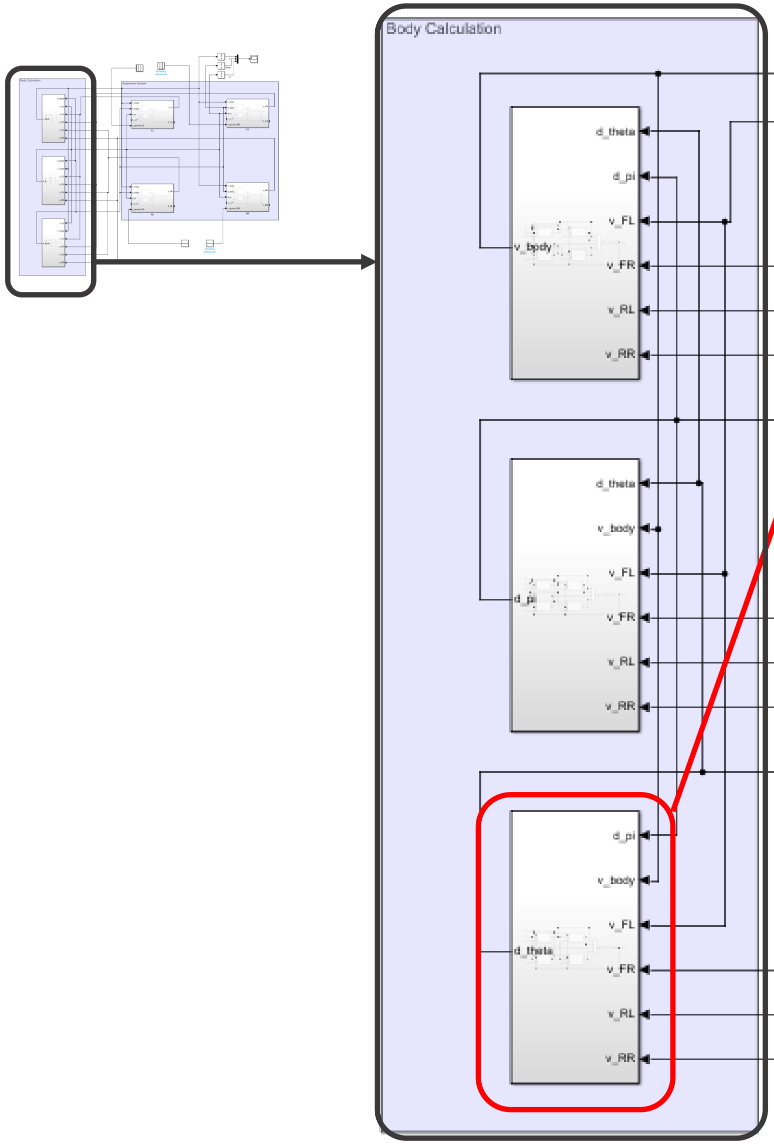


$\frac{d\varnothing}{dt}$ calculation

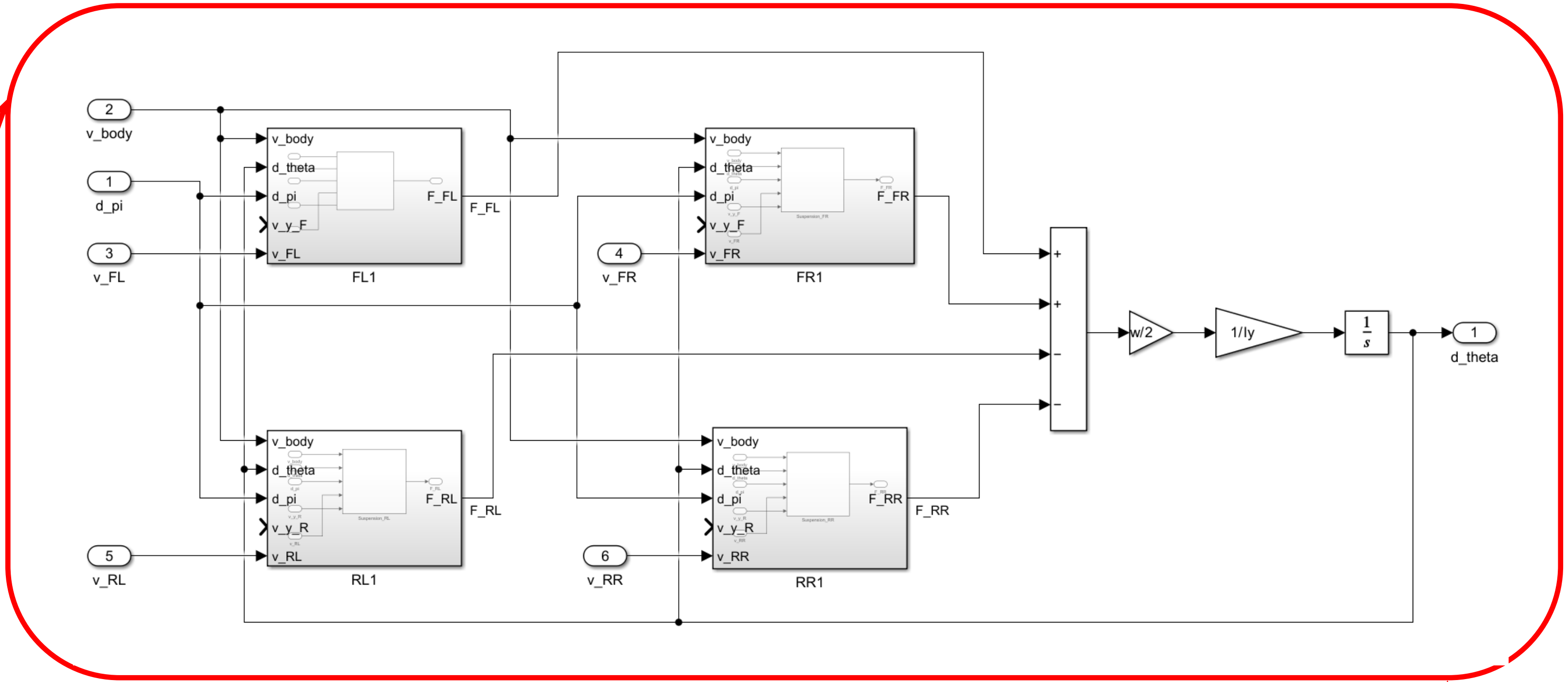


$$
\begin{aligned}
I_{xx}\ddot{\phi} = & -0.5w^2\left(K_{s,f}+K_{s,r}\right)\phi-0.5w^2\left(C_{s,f}+C_{s,r}\right)\dot{\phi}+0.5wK_{s,f}Z_{u,fl} \\
& + \ 0.5wC_{s,f}\dot{Z}_{u,fl}-0.5wK_{s,f}Z_{u,fr}-0.5wC_{s,f}\dot{Z}_{u,fr} \\
& + \ 0.5wK_{s,r}Z_{u,rl}+0.5wC_{s,r}\dot{Z}_{u,rl}-0.5wK_{s,r}Z_{u,rr}-0.5wC_{s,r}\dot{Z}_{u,rr} \\
& + \ \left(F_{pfl}+F_{prl}\right)\frac{w}{2}-\left(F_{pfr}+F_{prr}\right)\frac{w}{2}
\end{aligned}
$$

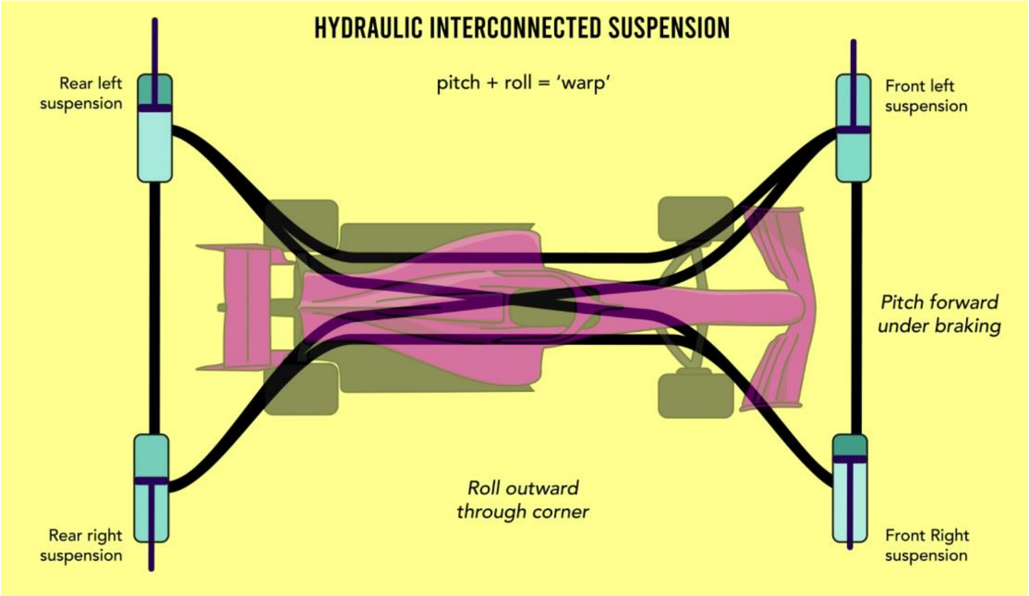
2 Full – Car Model



$\frac{d\theta}{dt}$ calculation



$$
\begin{aligned}
I_{yy}\ddot{\theta} = {} & 2\left(aK_{s,f}-bK_{s,r}\right)Z_s + 2\left(aC_{s,f}-bC_{s,r}\right)\dot{Z}_s - 2\left(a^2K_{s,f}+b^2K_{s,r}\right)\theta \\
& -2\left(a^2C_{s,f}+b^2C_{s,r}\right)\dot{\theta} - aK_{s,f}Z_{u,fl} - aC_{s,f}\dot{Z}_{u,fl} - aK_{s,f}Z_{u,fr} \\
& -aC_{s,f}\dot{Z}_{u,fr} + bK_{s,r}Z_{u,rl} + bC_{s,r}\dot{Z}_{u,rl} + bK_{s,r}Z_{u,rr} + bC_{s,r}\dot{Z}_{u,rr} \\
& -\left(F_{pfl}+F_{pfr}\right)l_f + \left(F_{prl}+F_{prr}\right)l_r
\end{aligned}
$$



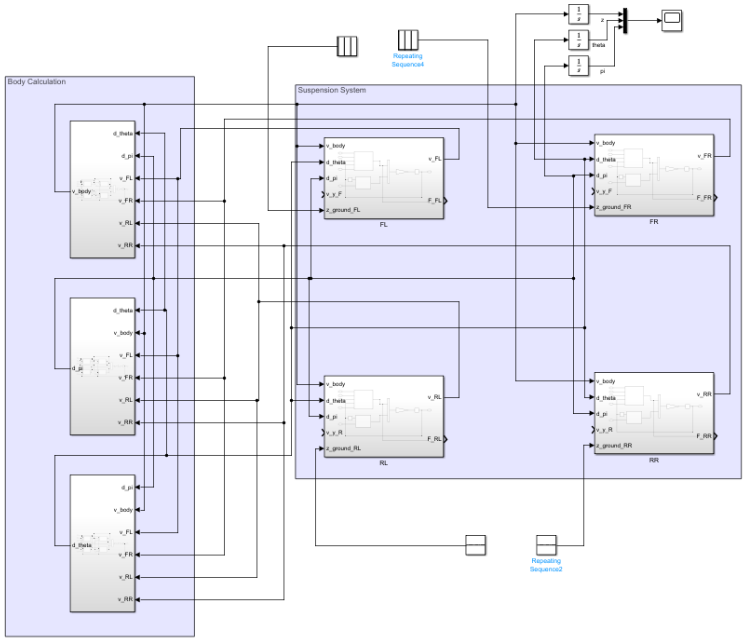
1

FRICS

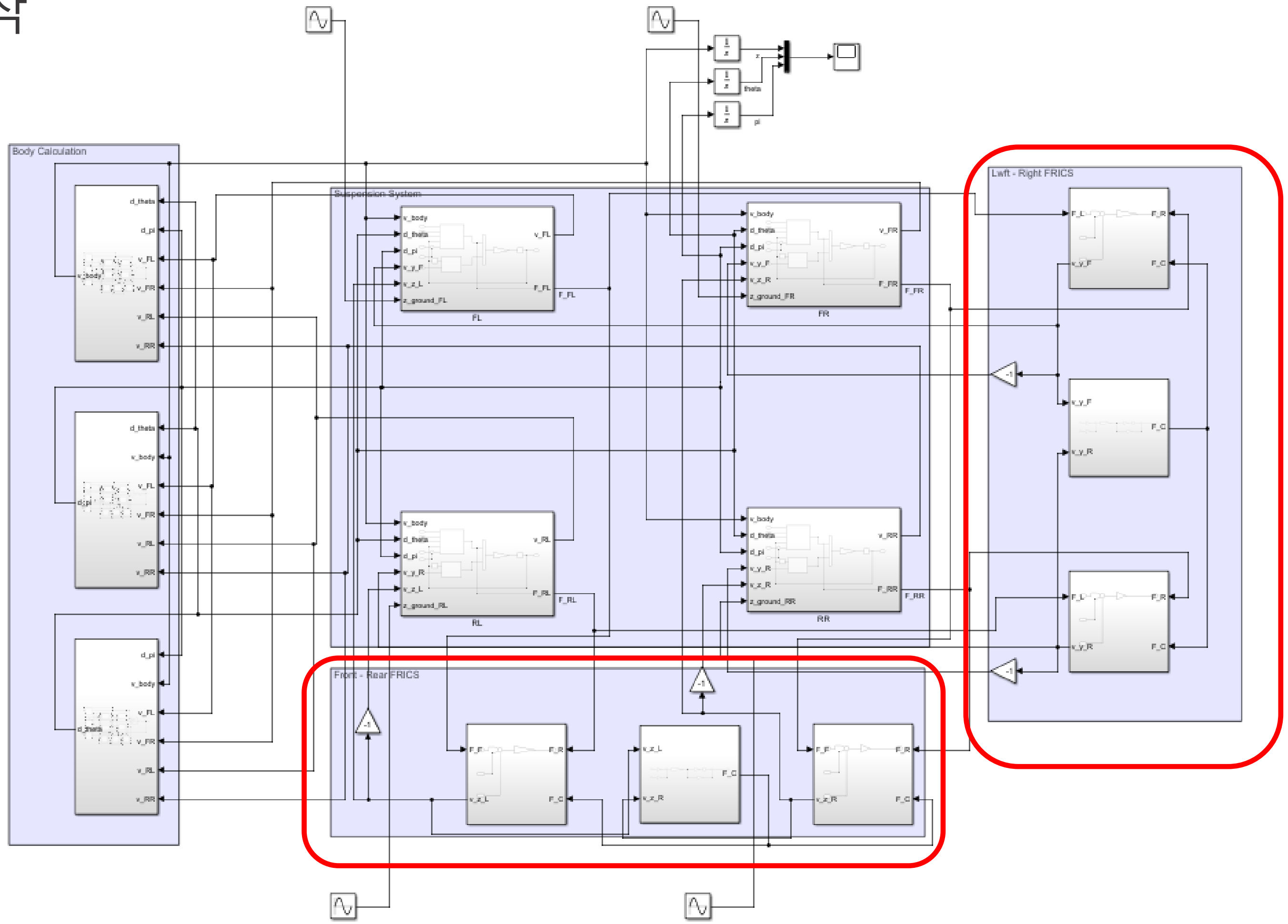
Front and Rear Interconnected Suspension

1 FRICS : Front and Rear Interconnected Suspension

지금까지 만들어온 **Full–Car Model**에 **FRICS** 장착

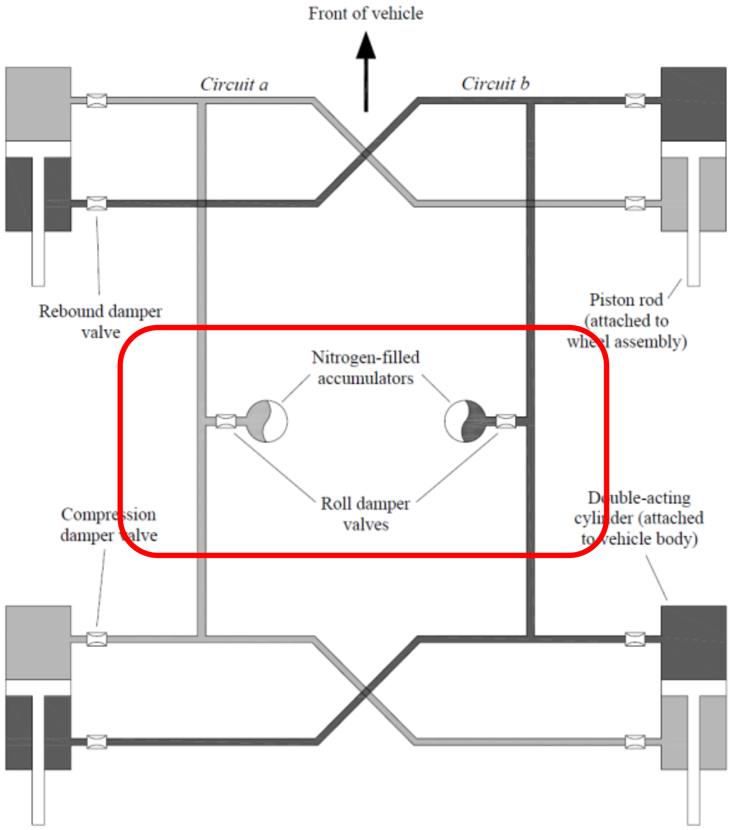


Full–Car Model



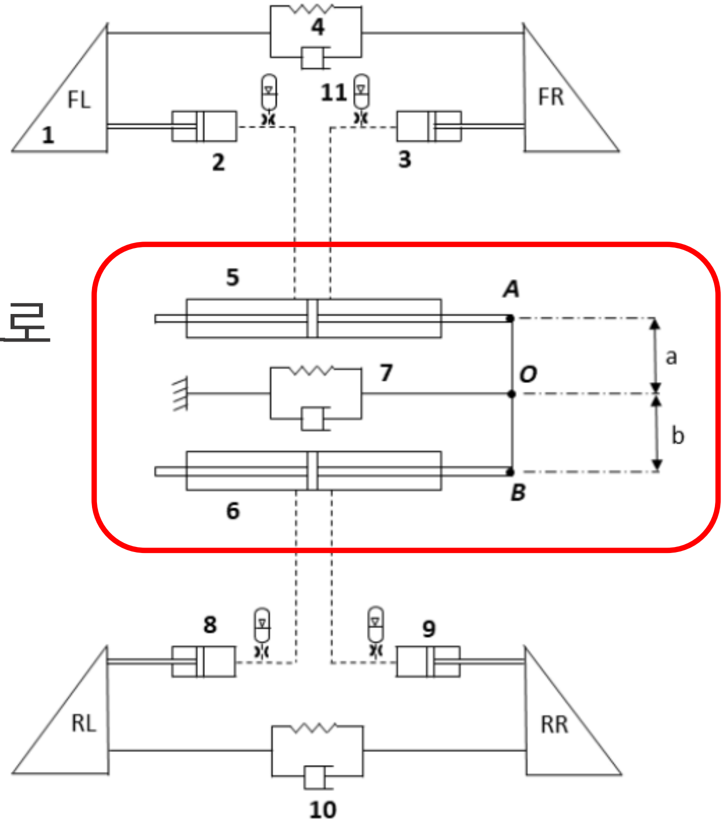
Full -Car Model + FRICS 2쌍

1 FRICS : Front and Rear Interconnected Suspension

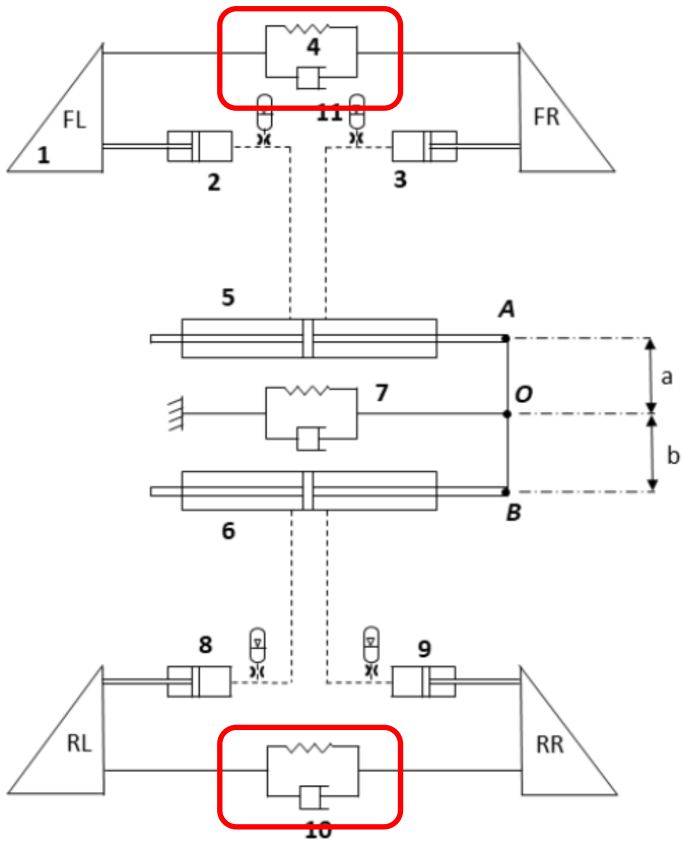


유체시스템의 accumulator를
Piston x2, Suspension system으로

Simplify

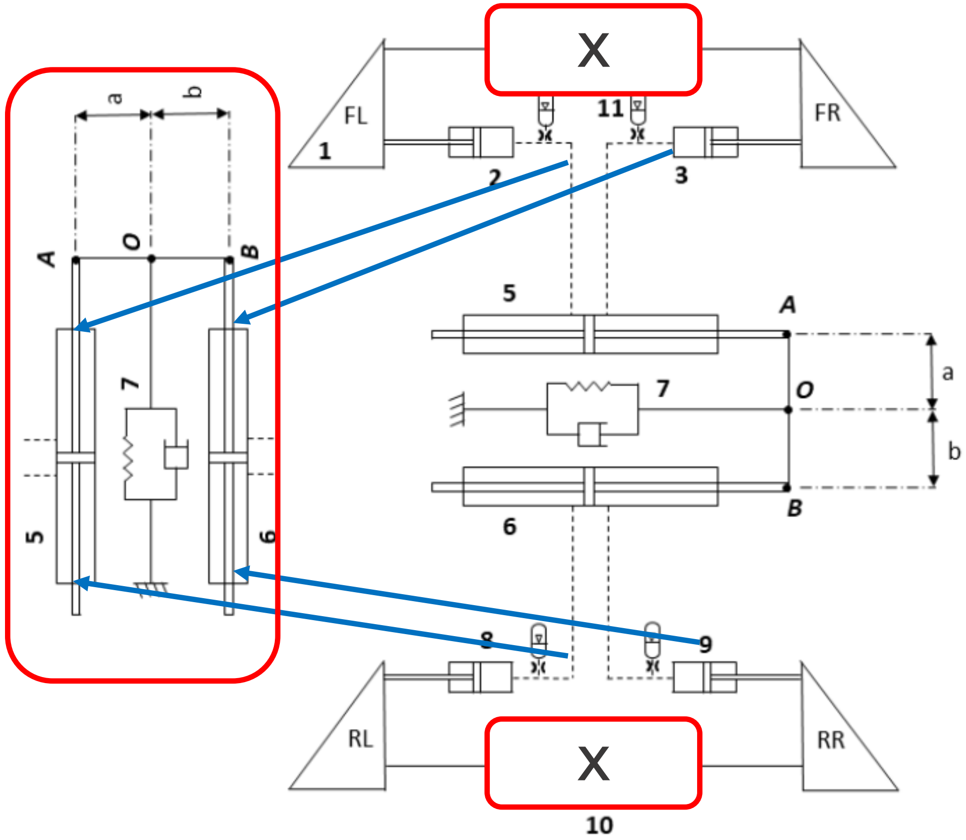


1 FRICS : Front and Rear Interconnected Suspension

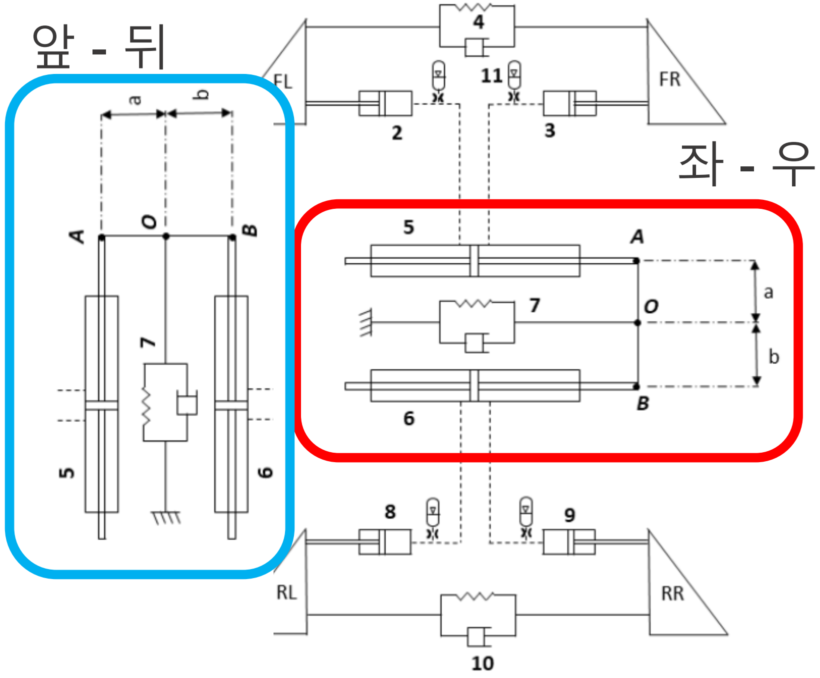


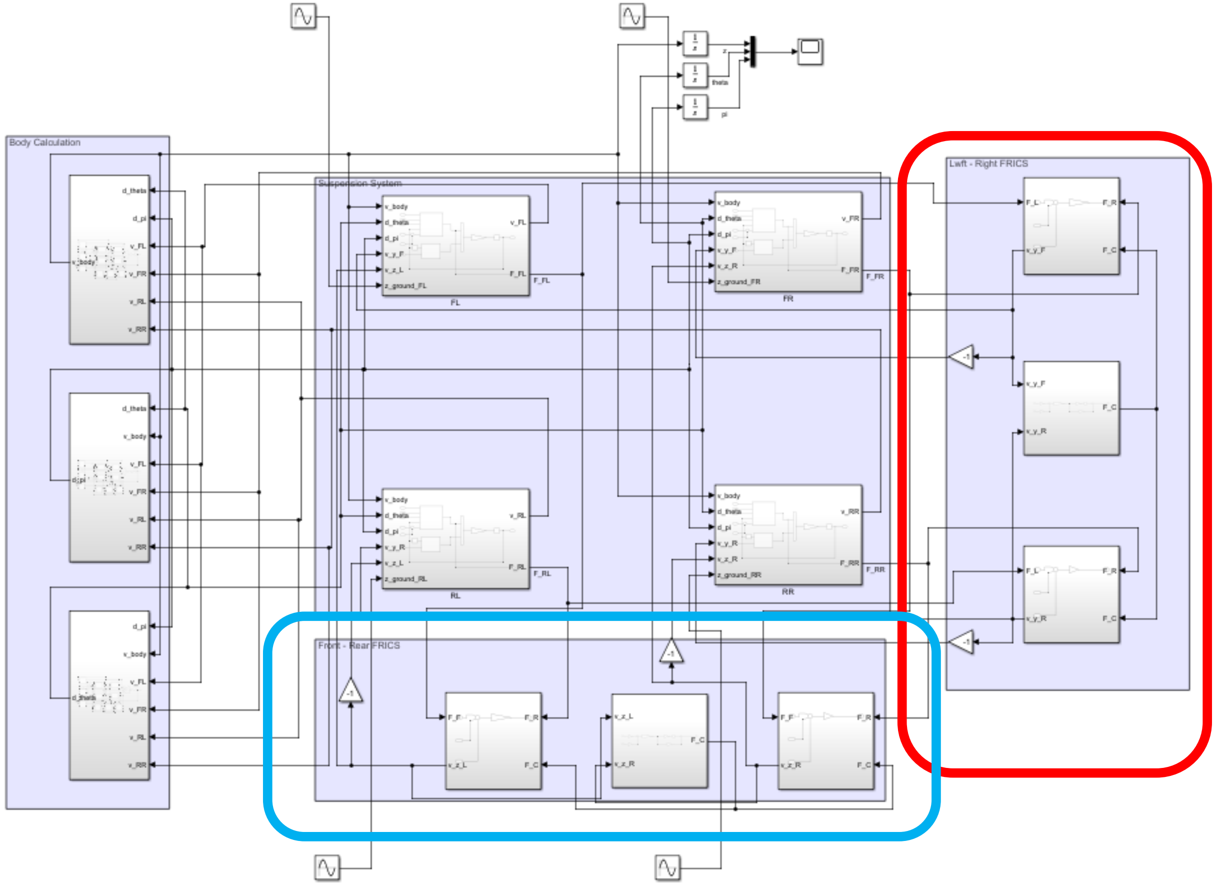
Heave spring-damper를 삭제

앞뒤의 움직임도 제어하는
FRICIS 추가

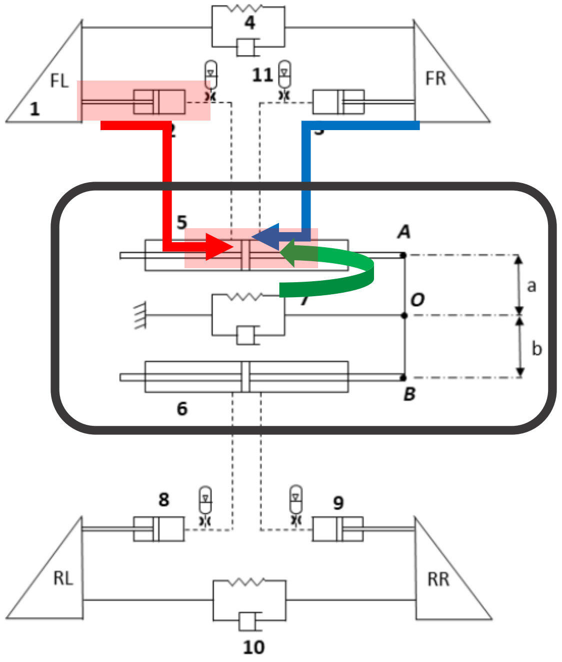


1 FRICS : Front and Rear Interconnected Suspension

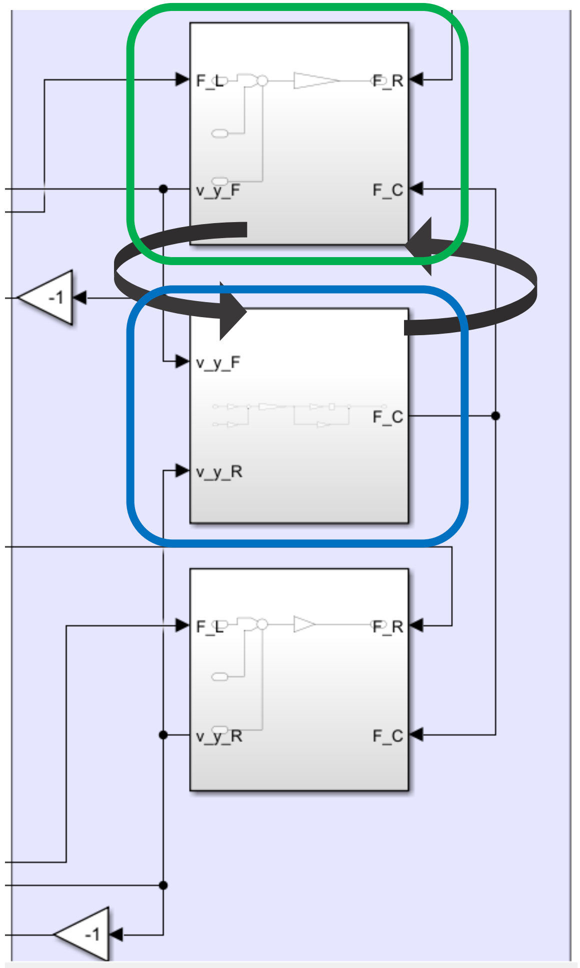


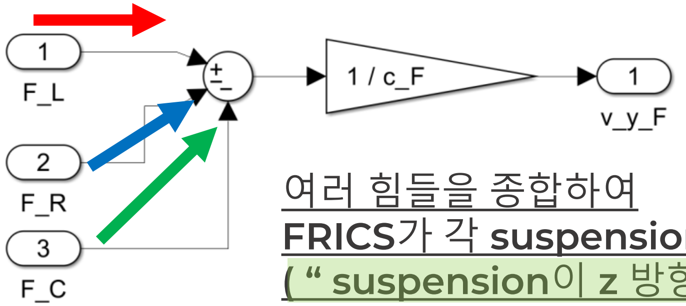


1 FRICS : Front and Rear Interconnected Suspension



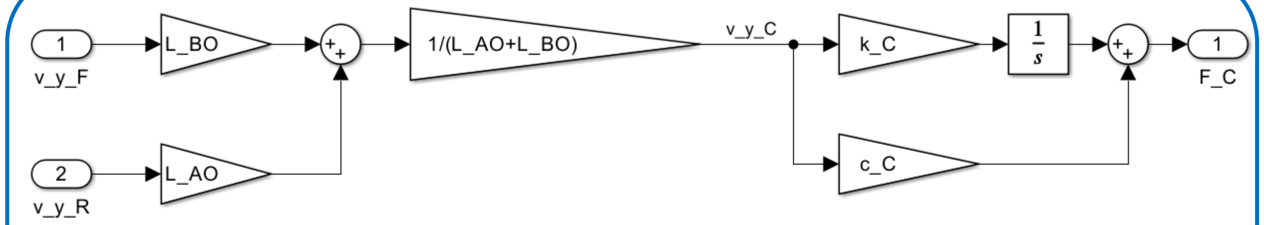
좌 – 우
FRICS





$$\sum F = c_F v$$

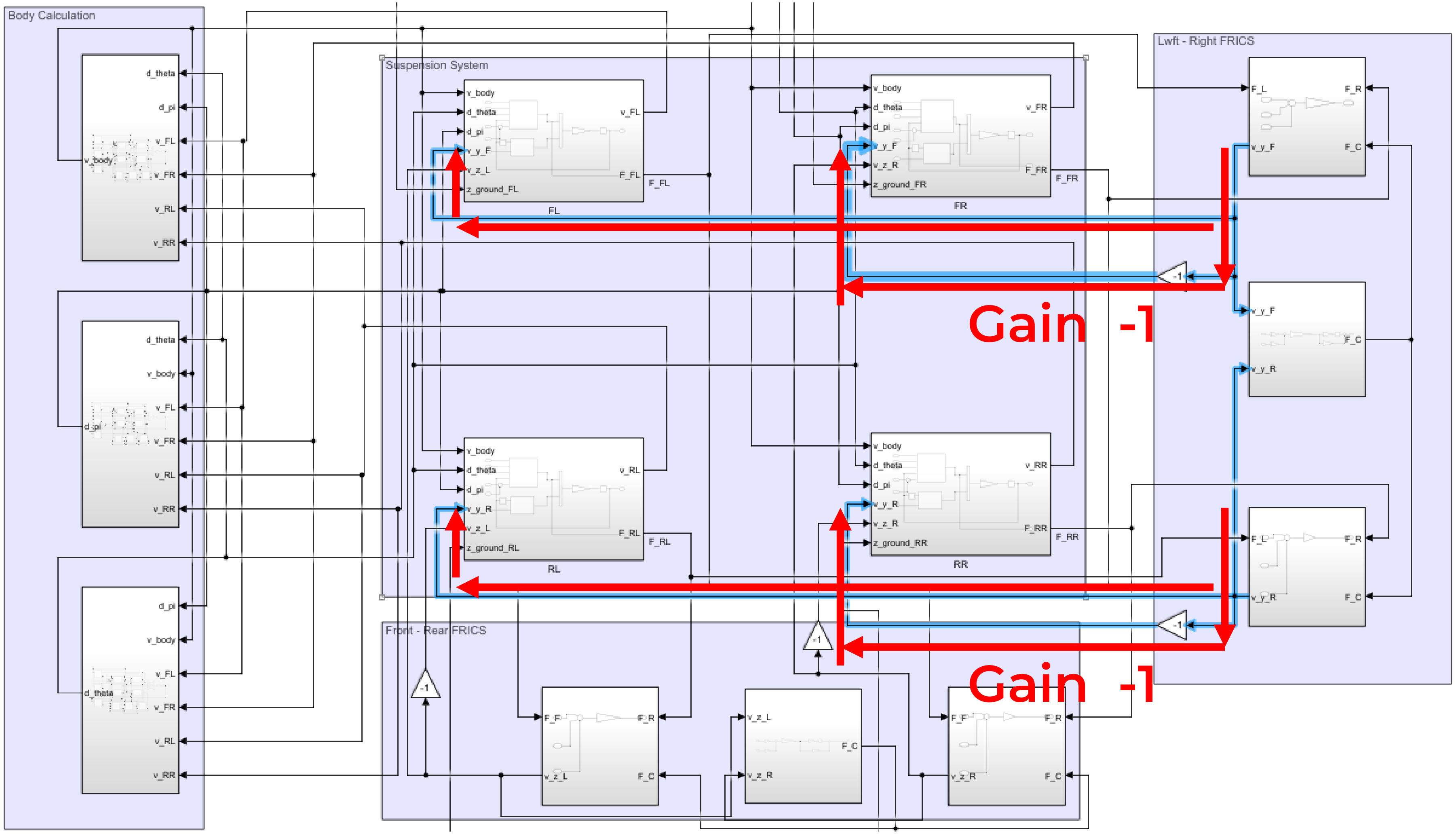
여러 힘들을 종합하여
FRICS가 각 suspension에 작용할 v 출력
(“ suspension이 z 방향으로 작용할 속도 ”)



위, 아래 피스톤의 거리비율 반영
가운데 스프링-댐퍼 시스템의 변위 확인

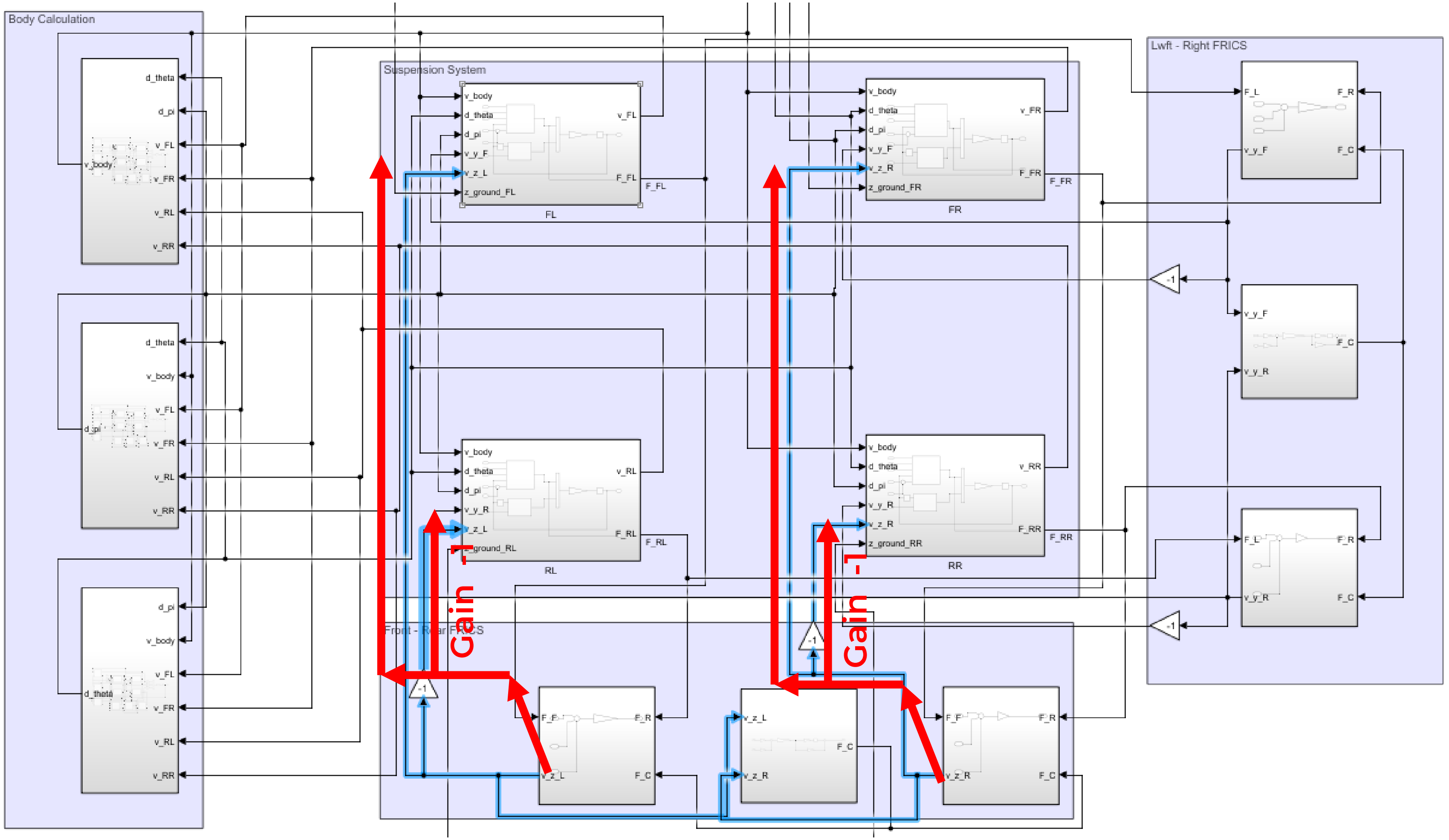
가운데 스프링-댐퍼 시스템이
FRICS의 피스톤에 작용할 힘 출력

1 FRICS : Front and Rear Interconnected Suspension



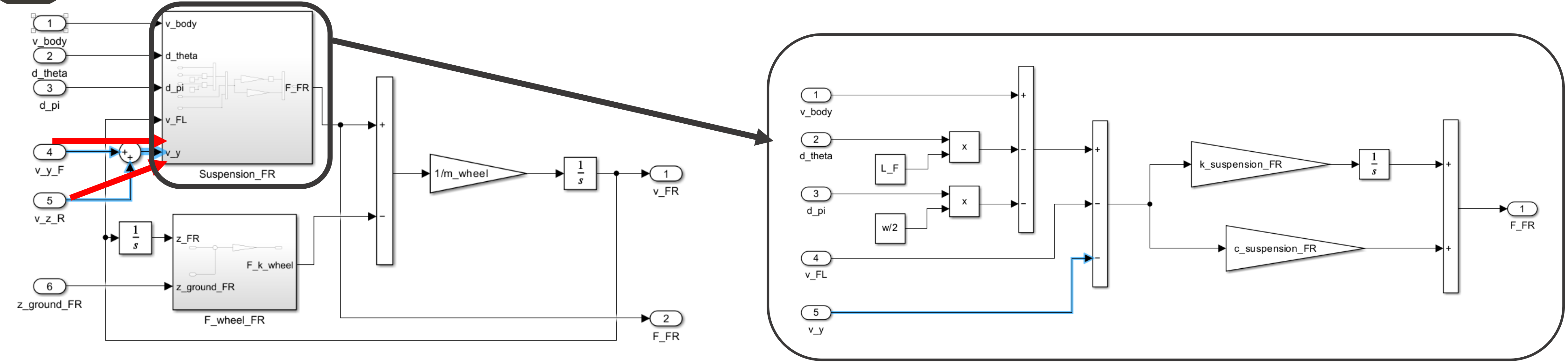
좌, 우 suspension system에 반대 부호의 v값을 전달

1 FRICS : Front and Rear Interconnected Suspension



Front-Rear FRICS도
동시에 작용

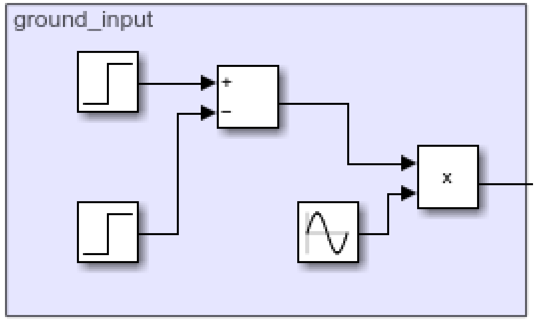
1 FRICS : Front and Rear Interconnected Suspension



FRICS의 output이 각 바퀴의 suspension system에 전달됨

(Left-Right FRICS, Front-Rear FRICS 두 개가 같이 전달됨)

1 FRICS : Front and Rear Interconnected Suspension



Full Car 와 Full Car with FRICS 를 비교

Input : 각각의 바퀴에 지면의 변위를 입력**, t = 1s ~ 2s**에 사인파 입력

Pitch를 **FRICS**가 효과적으로 감쇠해주는지를 확인하기 위해
앞바퀴와 뒷바퀴에 위상을 다르게 입력

진폭:
0.05
편향:
0
주파수(rad/s):
10*pi
위상(rad):
0

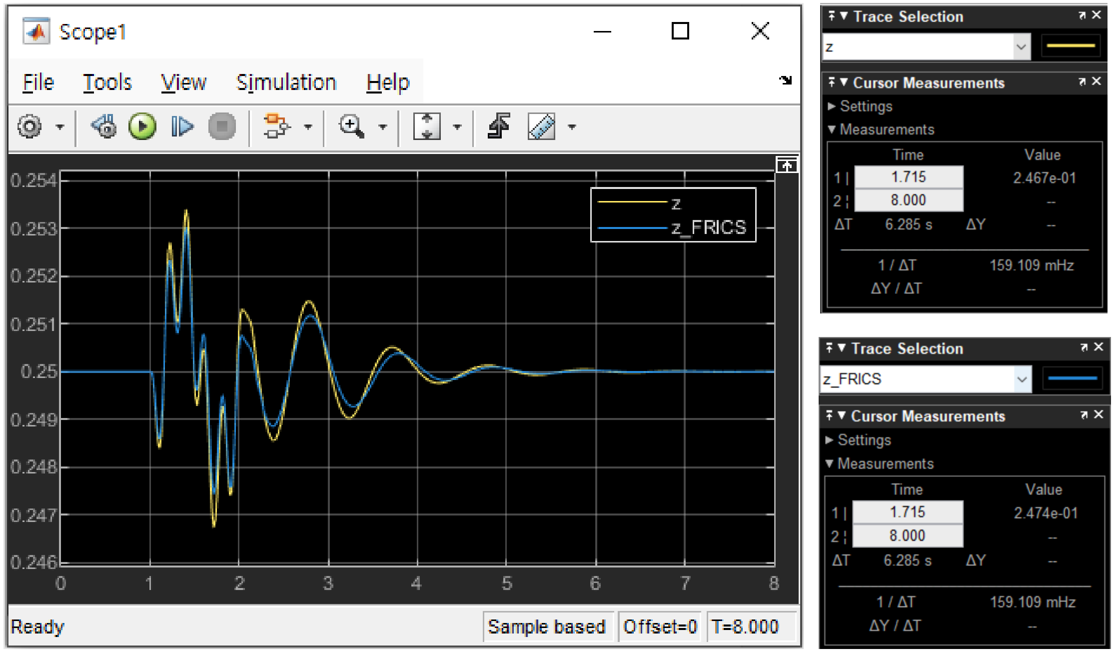
FL & FR input

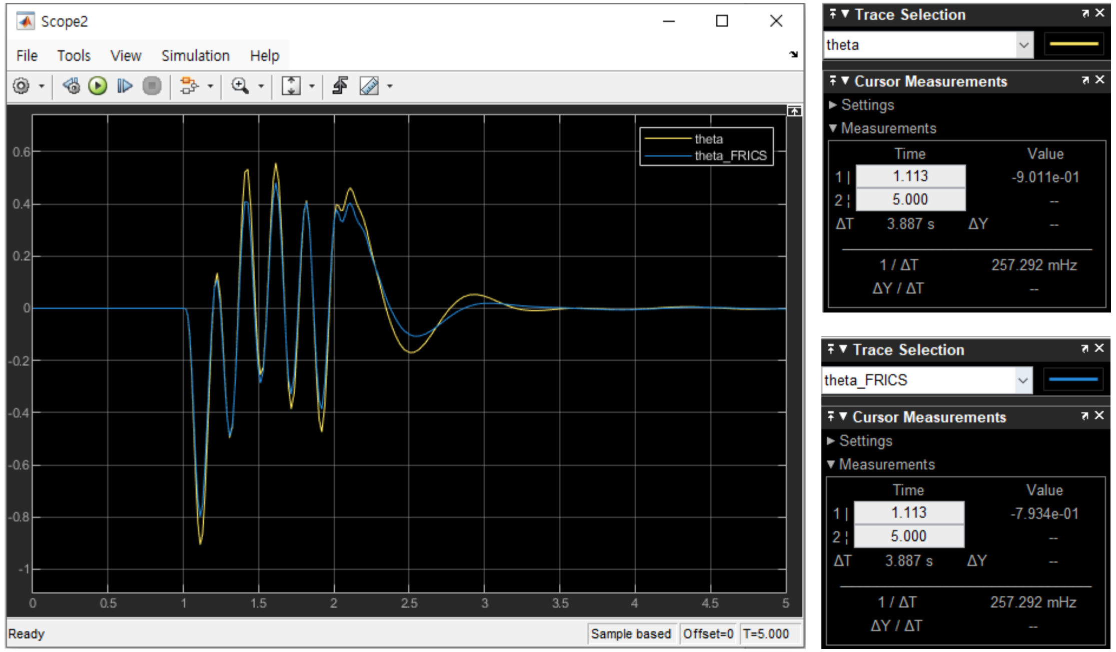
진폭:
0.05
편향:
0
주파수(rad/s):
10*pi
위상(rad):
-pi

RL & RR input

1 FRICS : Front and Rear Interconnected Suspension

Pitch 상황 – z변위 & theta

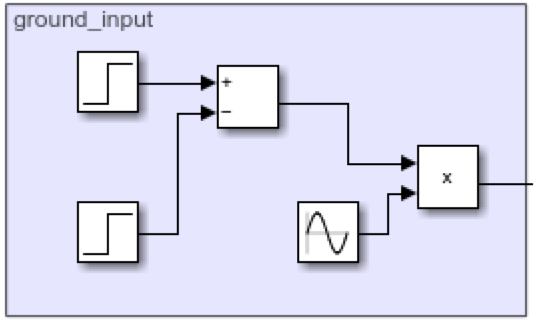




FRICS를 포함한 시스템에서 **z**변위의 최댓값이 **0.0026m,**
포함하지 않은 시스템에서의 최댓값이 **0.0033m**로
21.21%의 감쇠를 보임

FRICS를 포함한 시스템에서 **theta**변화의 최댓값이 **0.7934°,**
포함하지 않은 시스템에서의 최댓값이 **0.9011°**로
11.952%의 감쇠를 보임

1 FRICS : Front and Rear Interconnected Suspension



Full Car 와 Full Car with FRICS 를 비교

Input : 각각의 바퀴에 지면의 변위를 입력, **t = 1s ~ 2s**에 사인파 입력

Roll를 **FRICS**가 효과적으로 감쇠해주는지를 확인하기 위해
왼쪽바퀴와 오른쪽바퀴에 위상을 다르게 입력

진폭:
0.05
편향:
0
주파수(rad/s):
10*pi
위상(rad):
0

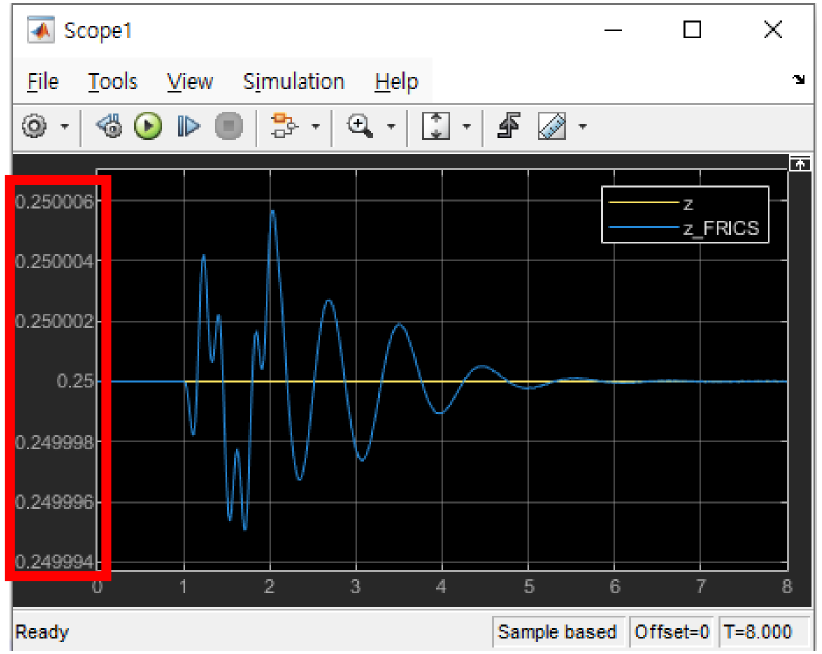
FL & RL input

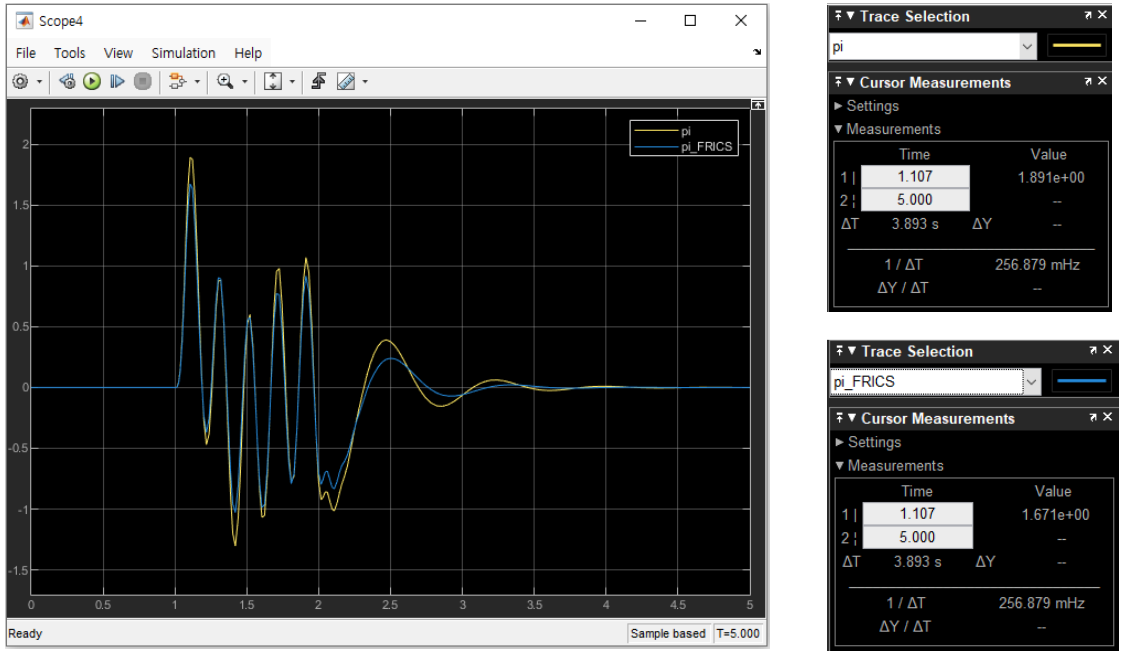
진폭:
0.05
편향:
0
주파수(rad/s):
10*pi
위상(rad):
-pi

FR & RR input

1 FRICS : Front and Rear Interconnected Suspension

Roll 상황 – z변위 & pi



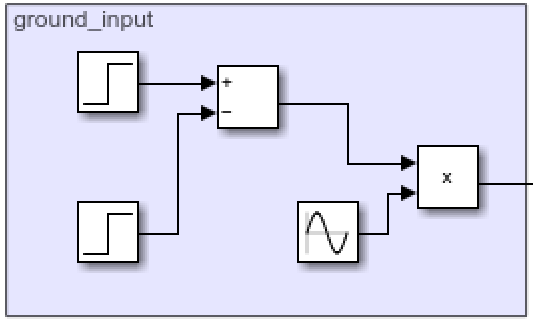


Roll 상황에서는 **body**의 무게중심의 **z**변위가 **0**이 되어야 하지만, **FRICS** 시스템이 포함되었을 때는 최대 변위가 약 **0.000005m**로 수치적 오류가 발생했다고 판단함

FRICS를 포함한 시스템에서 **pi**변화의 최댓값이 **1.671°**, 포함하지 않은 시스템에서의 최댓값이 **1.897°**로 **11.914%**의 감쇠를 보임

1 FRICS : Front and Rear Interconnected Suspension

Full Car 와 **Full Car with FRICS** 를 비교



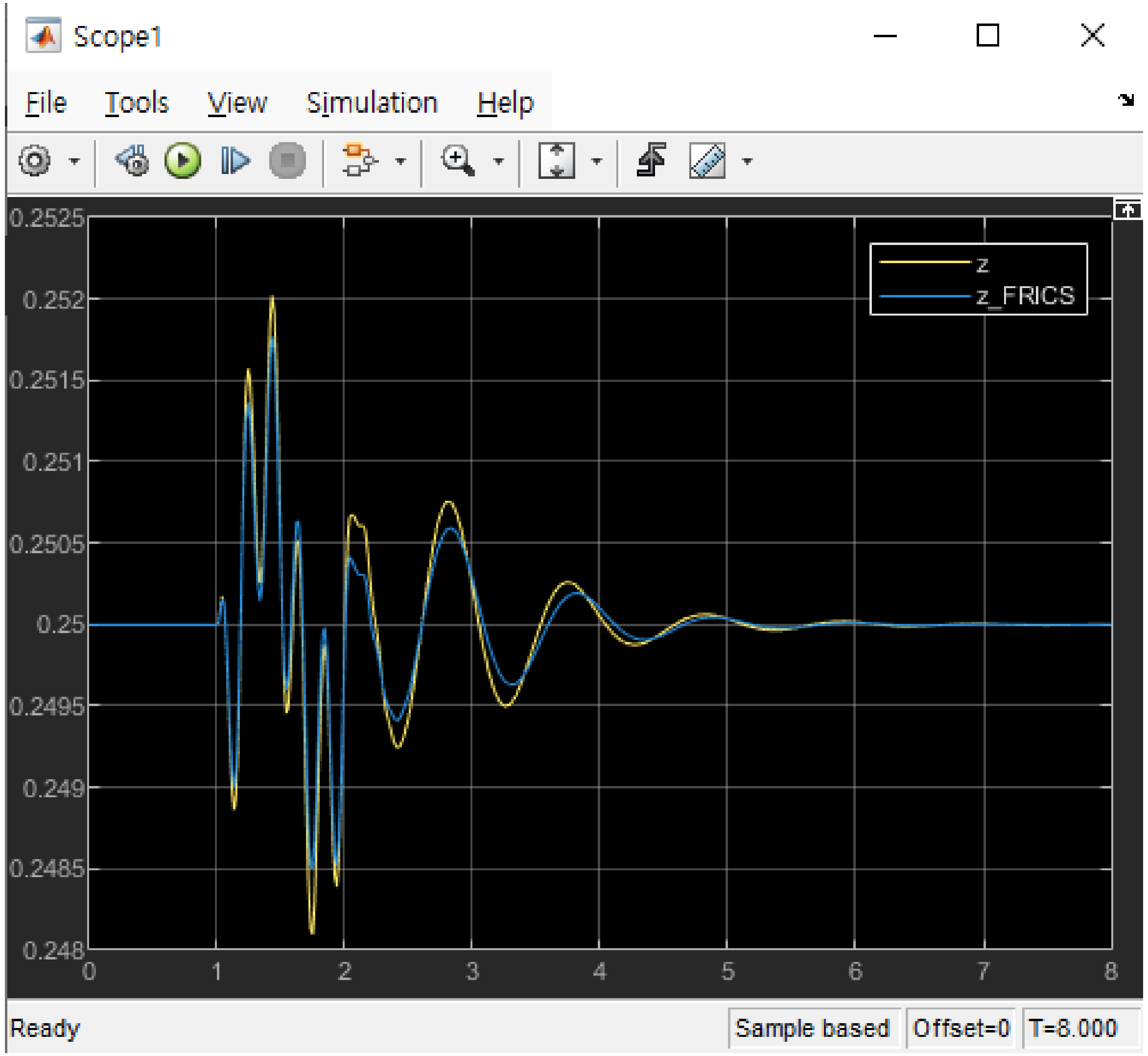
Input : 각각의 바퀴에 지면의 변위를 입력**, t = 1s ~ 2s**에 사인파 입력

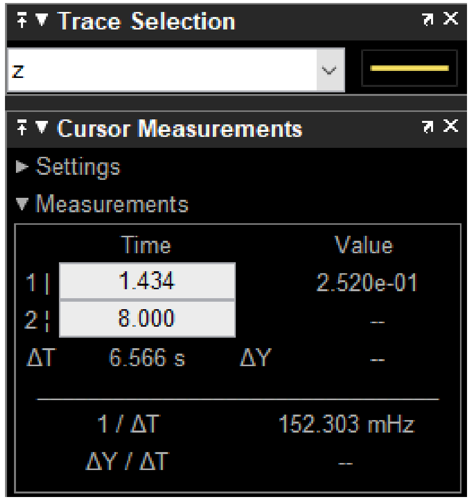
<u>Warp(Pitch + Roll)</u>을 **FRICS**가 효과적으로 감쇠해주는지를 확인하기 위해
각 바퀴에 위상이 다르게 입력

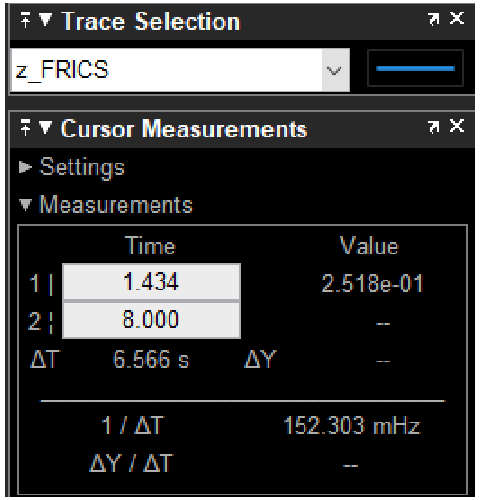
	FL input	FR input	RL input	RR input
진폭:	0.05	0.05	0.05	0.05
편향:	0	0	0	0
주파수(rad/s):	10*pi	10*pi	10*pi	10*pi
위상(rad):	0	-0.5*pi	-pi	-1.5*pi

1 FRICS : Front and Rear Interconnected Suspension

Warp(Pitch + Roll) 상황 – z변위



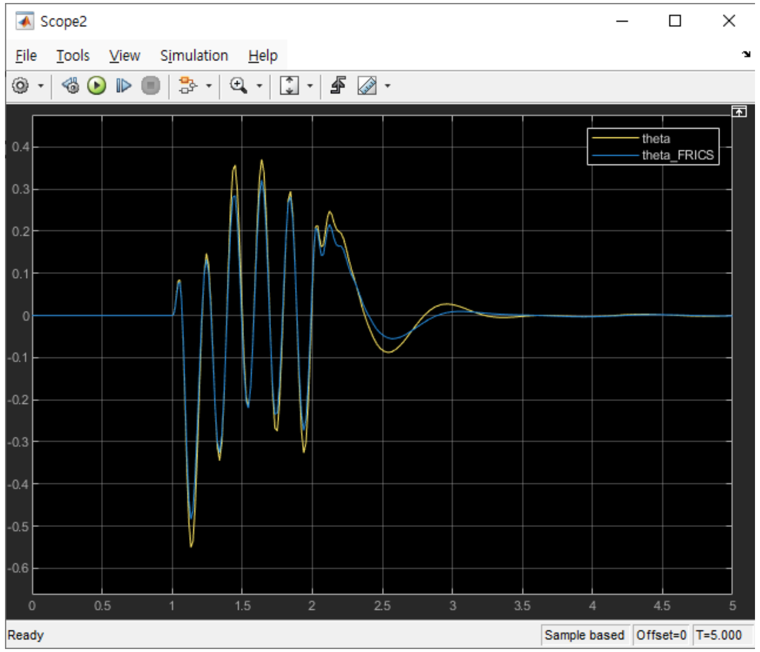


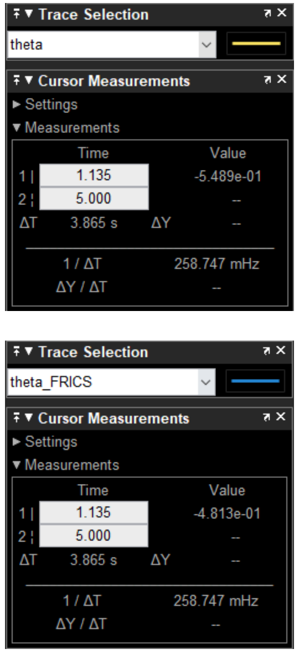


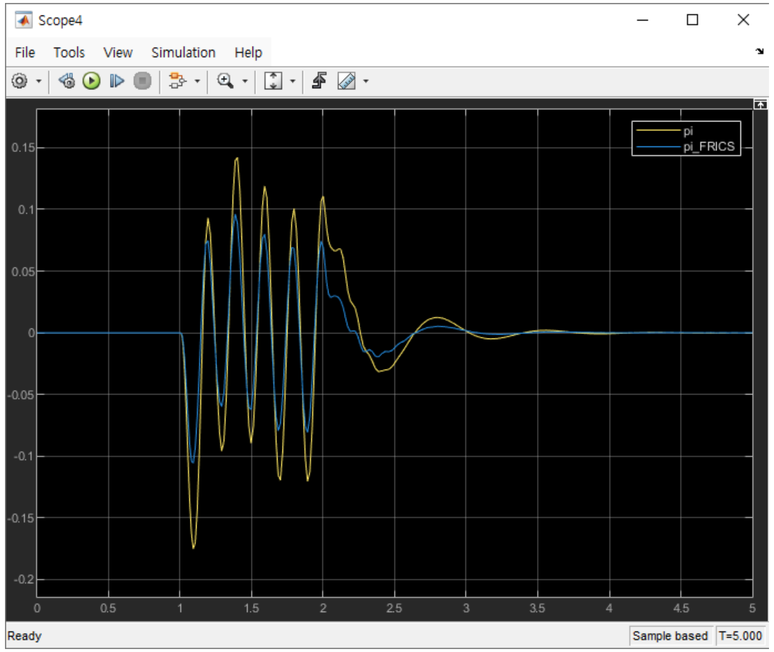
FRICS를 포함한 시스템에서 z변위의 최댓값이 **0.0018m,** 포함하지 않은 시스템에서의 최댓값이 **0.002m**로 10%의 감쇠를 보임

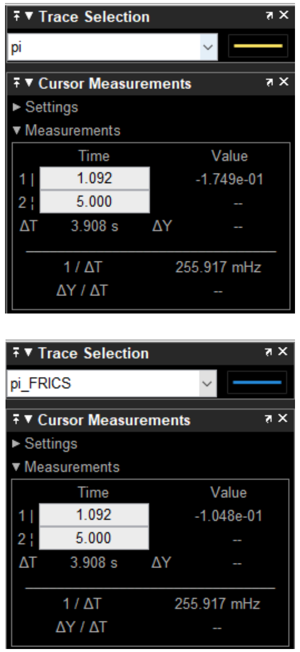
1 FRICS : Front and Rear Interconnected Suspension

Warp(Pitch + Roll) 상황 – theta & pi









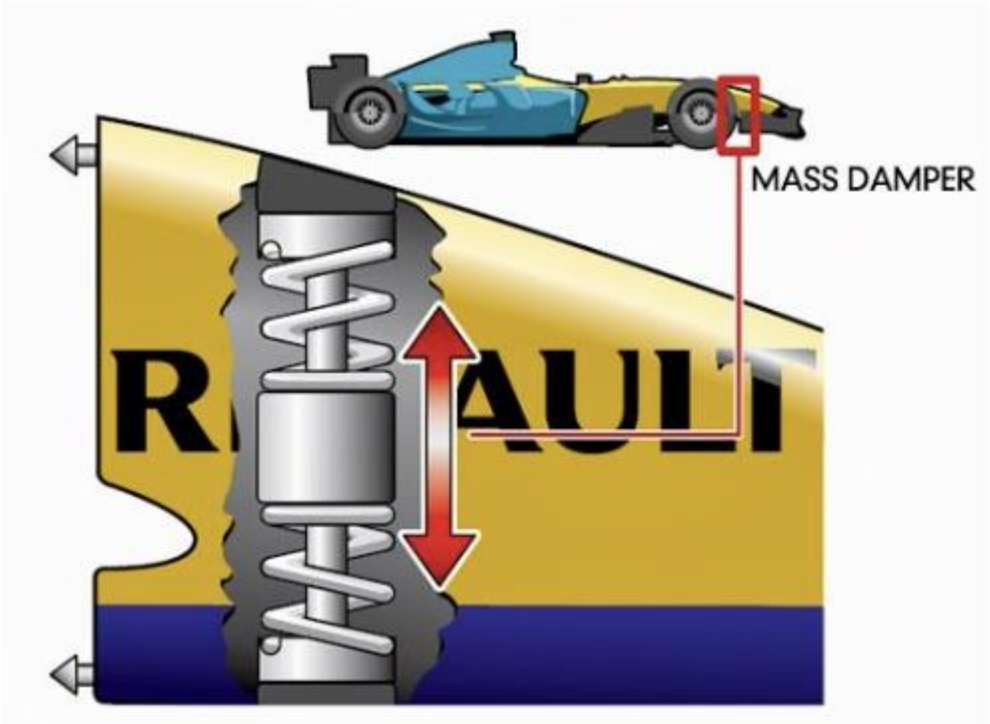
FRICS를 포함한 시스템에서 **theta**변화의 최댓값이 **0.4813°,**
포함하지 않은 시스템에서의 최댓값이 **0.5489°**로
12.315%의 감쇠를 보임

FRICS를 포함한 시스템에서 **theta**변화의 최댓값이 **0.1048°,**
포함하지 않은 시스템에서의 최댓값이 **0.1749°**로
40.08%의 감쇠를 보임

3

Mass Damper

3 Mass Damper

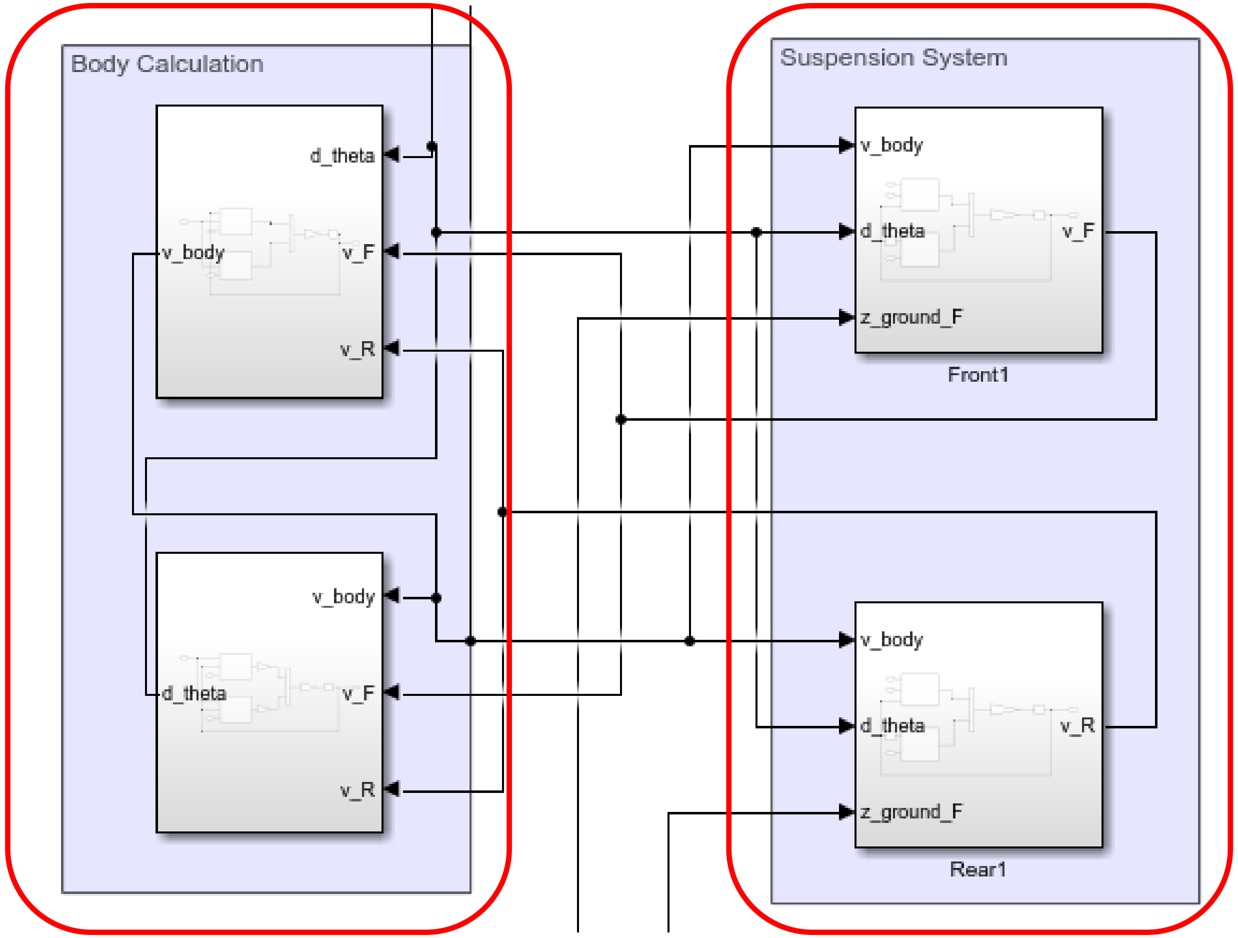


Mass Damper : 진동을 상쇄시키기 위한 장치

가속 & 제동 시 전방 하중의 이동에 따른 **Pitch** 변화 감소

지상고 일정하게 유지
→ **Downforce** 일정하게 유지, 안정성 향상

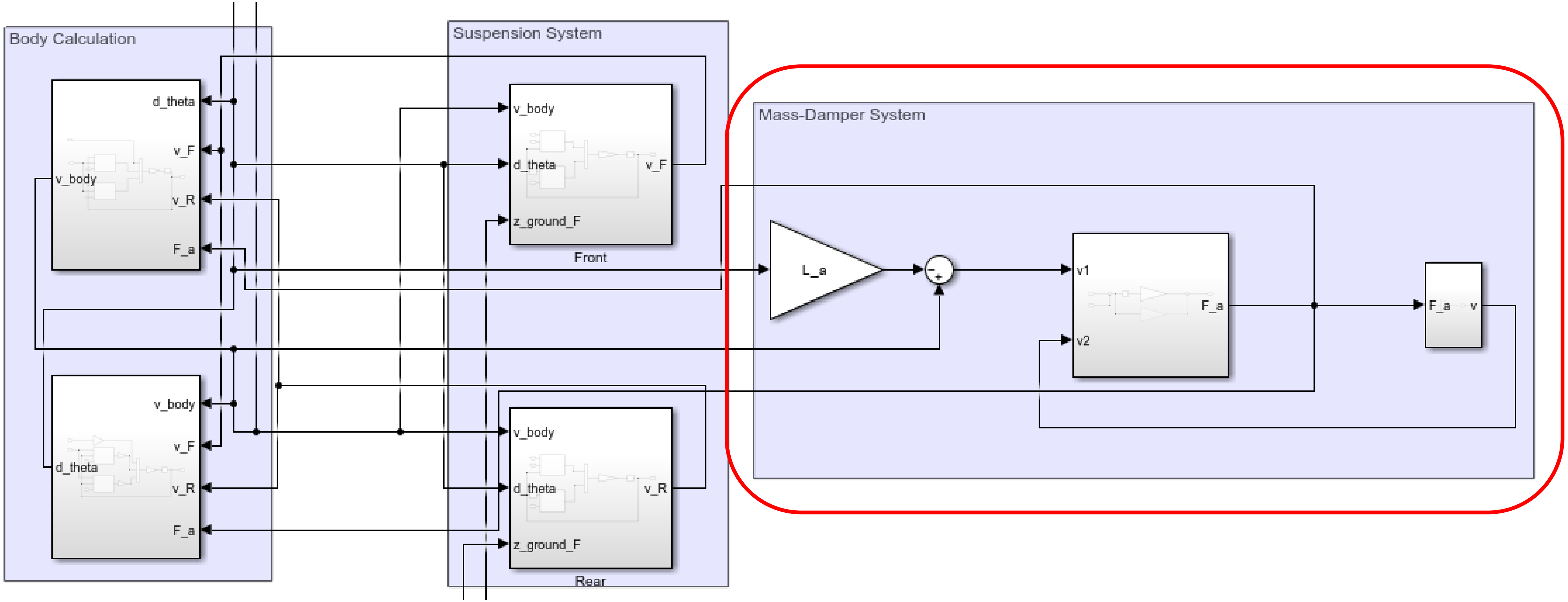
3 Mass Damper – Half Car Model



Body Calculation

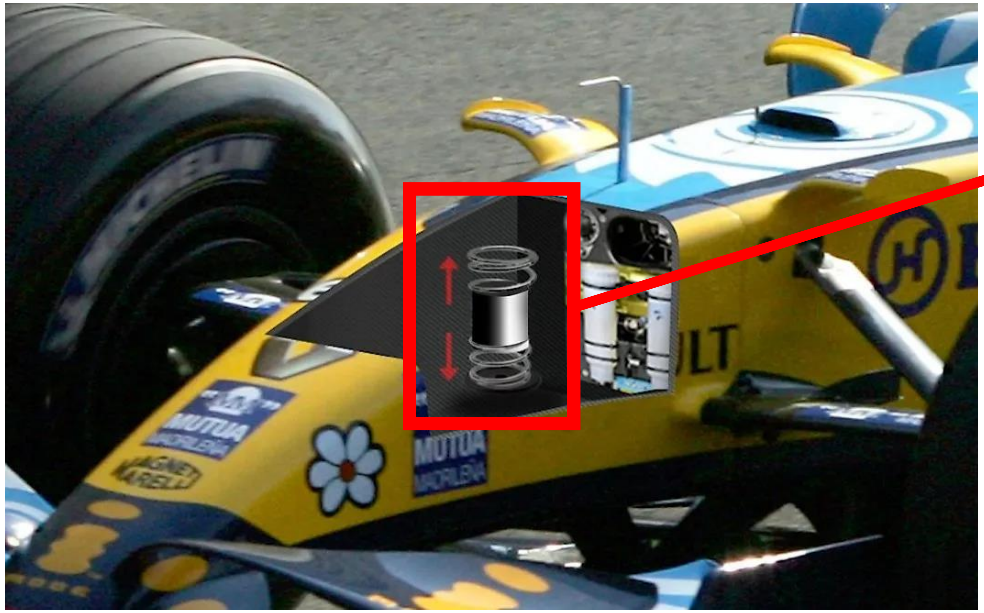
Suspension System

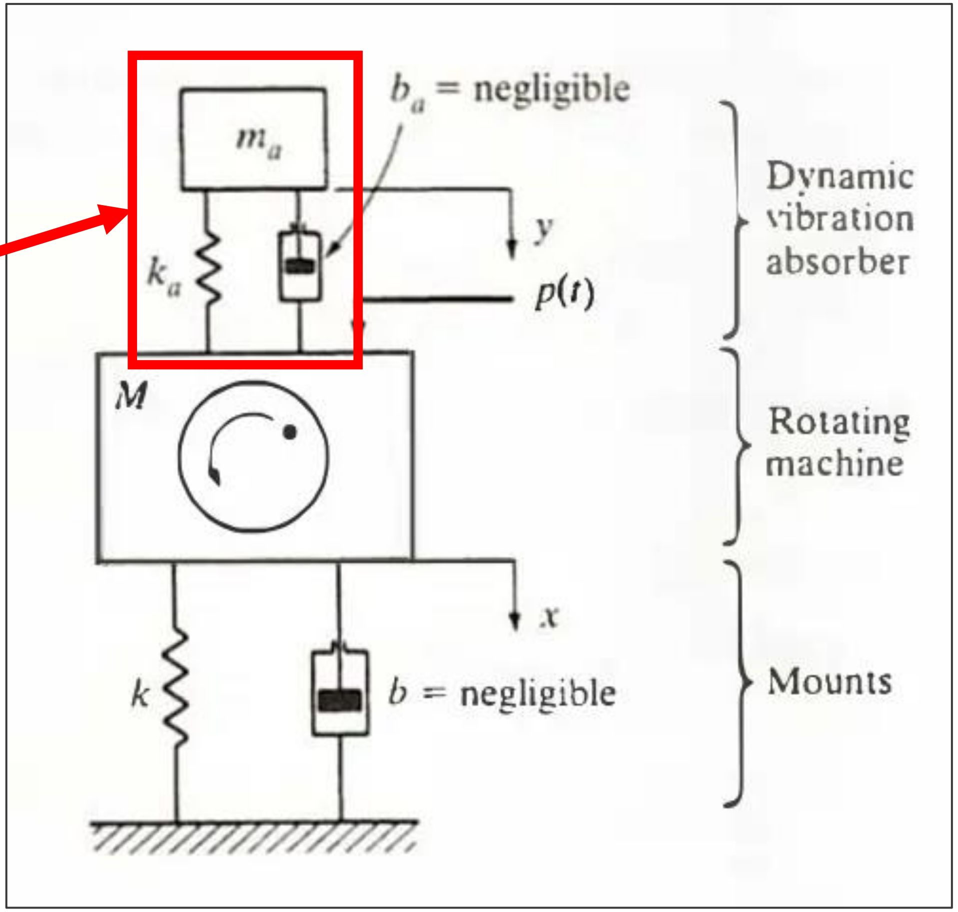
3 Mass Damper



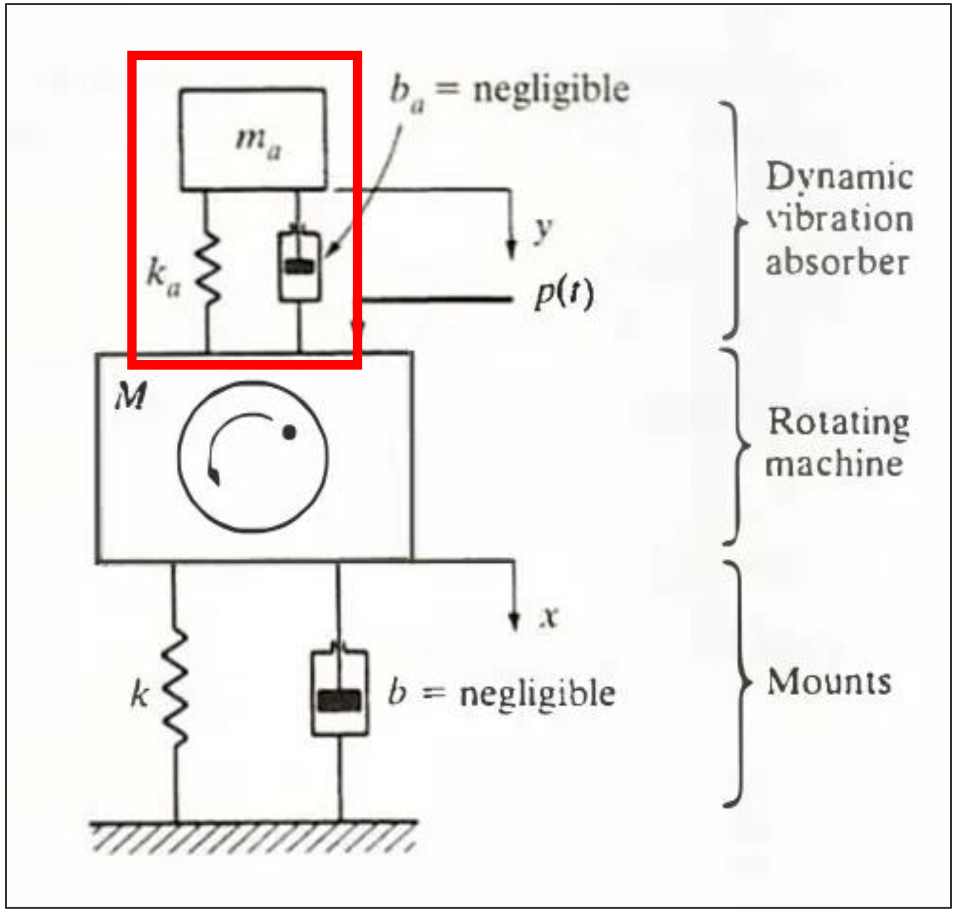
Half–Car Model + Mass Damper

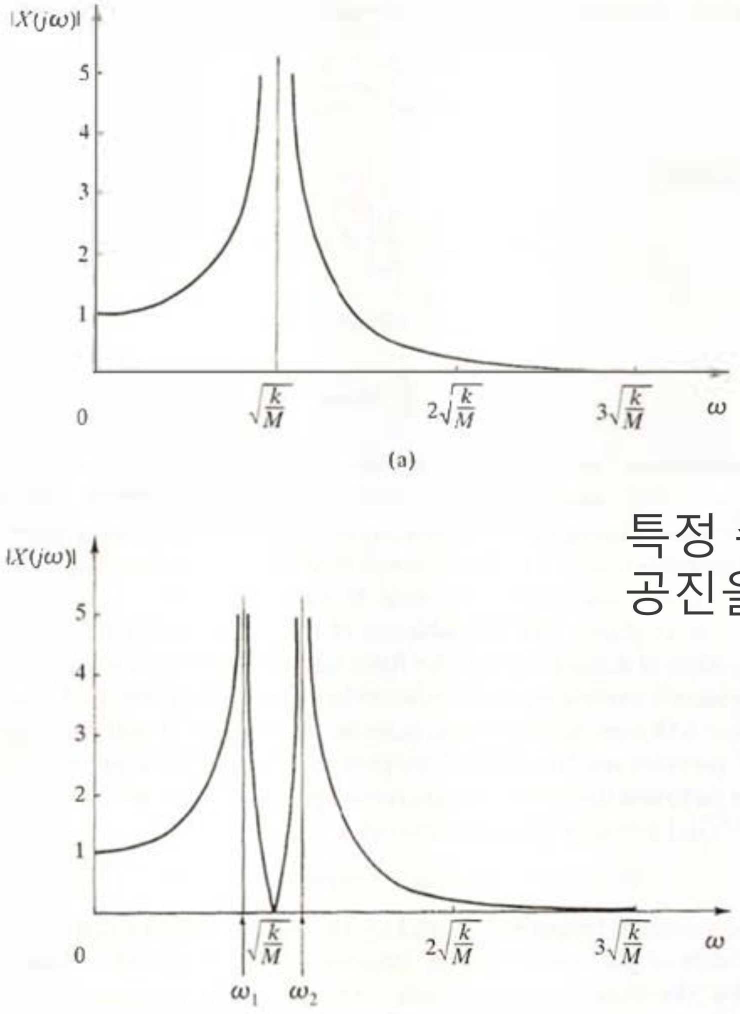
3 Mass Damper





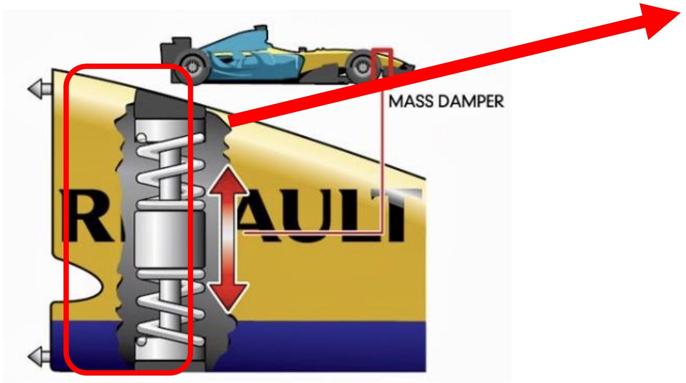
3 Mass Damper

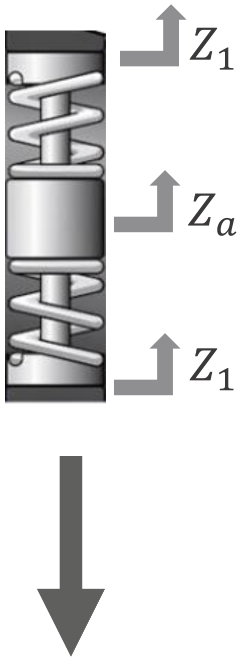




특정 주파수에서의
공진을 대폭 줄여줌

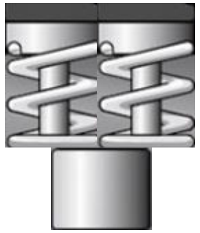
3 Mass Damper – Modeling





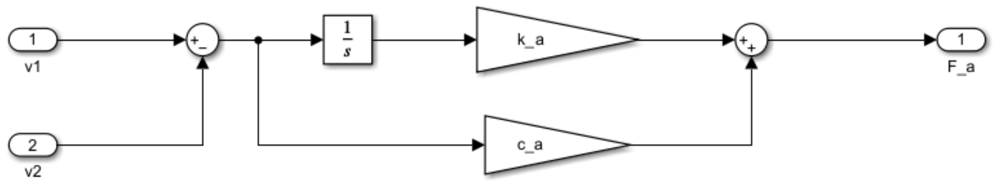
$$m_a a_a = k_1(Z_1 - Z_a) + k_2(Z_1 - Z_a) + c_1(Z_1 - Z_a) + c_2(Z_1 - Z_a)$$

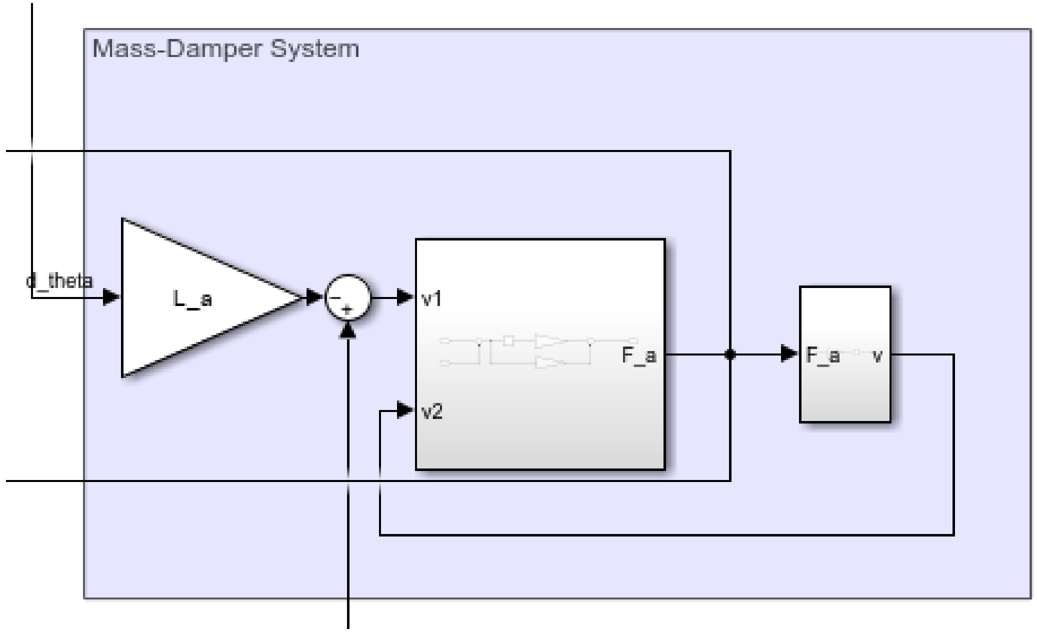
$$m_a a_a = (k_1 + k_2)(Z_1 - Z_a) + (c_1 + c_2)(Z_1 - Z_a)$$



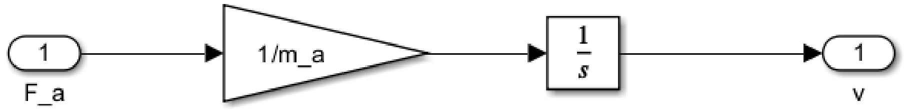
$$m_a a_a = k_{eq}(Z_1 - Z_a) + c_{eq}(Z_1 - Z_a),$$
$$k_{eq} = k_1 + k_2, \qquad c_{eq} = c_1 + c_2$$

3 Mass Damper





각속도에 무게중심에서
Mass Damper까지의 거리**(L_a)**를 곱해 **v(v1)**를 입력,
이를 통해 **Mass Damper**에서의 힘**(F_a)** 출력



위에서 구한 힘**(F_a)**를 입력,
이를 통해 **Mass Damper**의 **z**방향 속도 출력

3 Mass Damper

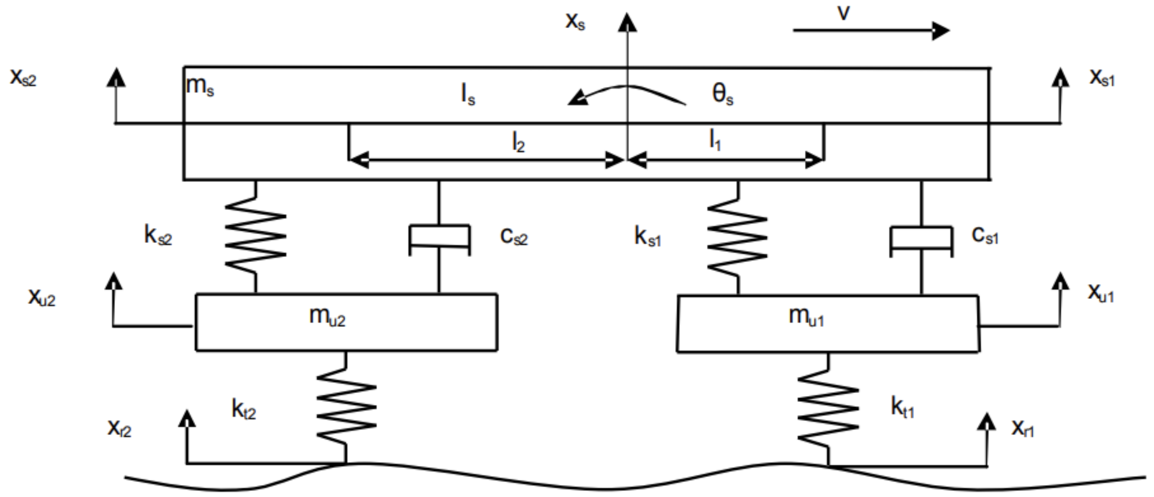


Figure 1. The half-car model of the vehicle.

<u>시스템 해석 활용</u>

4개의 subsystem : body (x_s, θ_s), tire(x_{u1}, x_{u2})
에서의 식을 통합하여 matrix 형태로 정리

$$X = [x_s \quad \theta_s \quad x_{u1} \quad x_{u2}]^T$$

$$\begin{bmatrix} m_s & 0 & 0 & 0 \\ 0 & I_s & 0 & 0 \\ 0 & 0 & m_{u1} & 0 \\ 0 & 0 & 0 & m_{u2} \end{bmatrix} \ddot{X} + \begin{bmatrix} c_{s1}+c_{s2} & -l_1c_{s1}+l_2c_{s2} & -c_{s1} & -c_{s2} \\ -l_1c_{s1}+l_2c_{s2} & l_1^2c_{s1}+l_2^2c_{s2} & l_1c_{s1} & -l_2c_{s2} \\ -c_{s1} & l_1c_{s1} & c_{s1} & 0 \\ -c_{s2} & -l_2c_{s2} & 0 & c_{s2} \end{bmatrix} \dot{X}$$

$$+\begin{bmatrix} k_{s1}+k_{s2} & -l_1k_{s1}+l_2k_{s2} & -k_{s1} & -k_{s2} \\ -l_1k_{s1}+l_2k_{s2} & l_1^2k_{s1}+l_2^2k_{s2} & l_1k_{s1} & -l_2k_{s2} \\ -k_{s1} & l_1k_{s1} & k_{s1}+k_{t2} & 0 \\ -k_{s2} & -l_2k_{s2} & 0 & k_{s2}+k_{t2} \end{bmatrix} X = \begin{bmatrix} 0 \\ 0 \\ k_{t1}x_{r1} \\ k_{t2}x_{r2} \end{bmatrix}$$

3 Mass Damper

MATLAB를 활용하여

Natural Frequency 구함

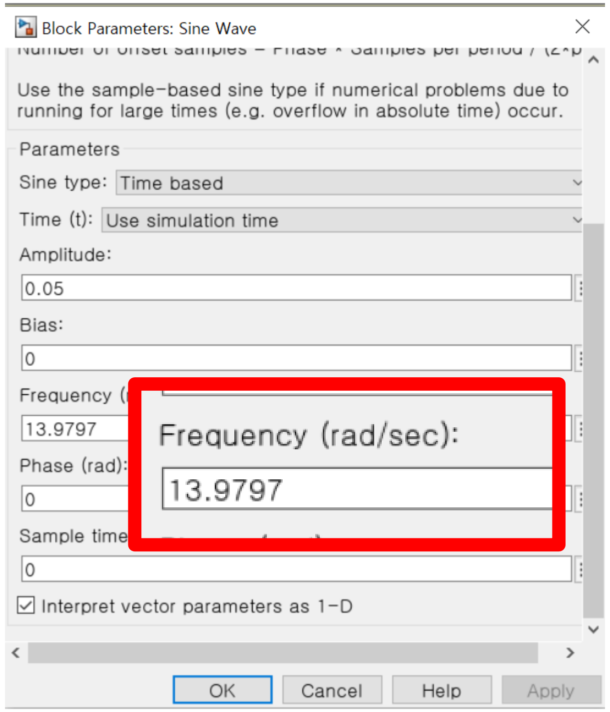
명령 창

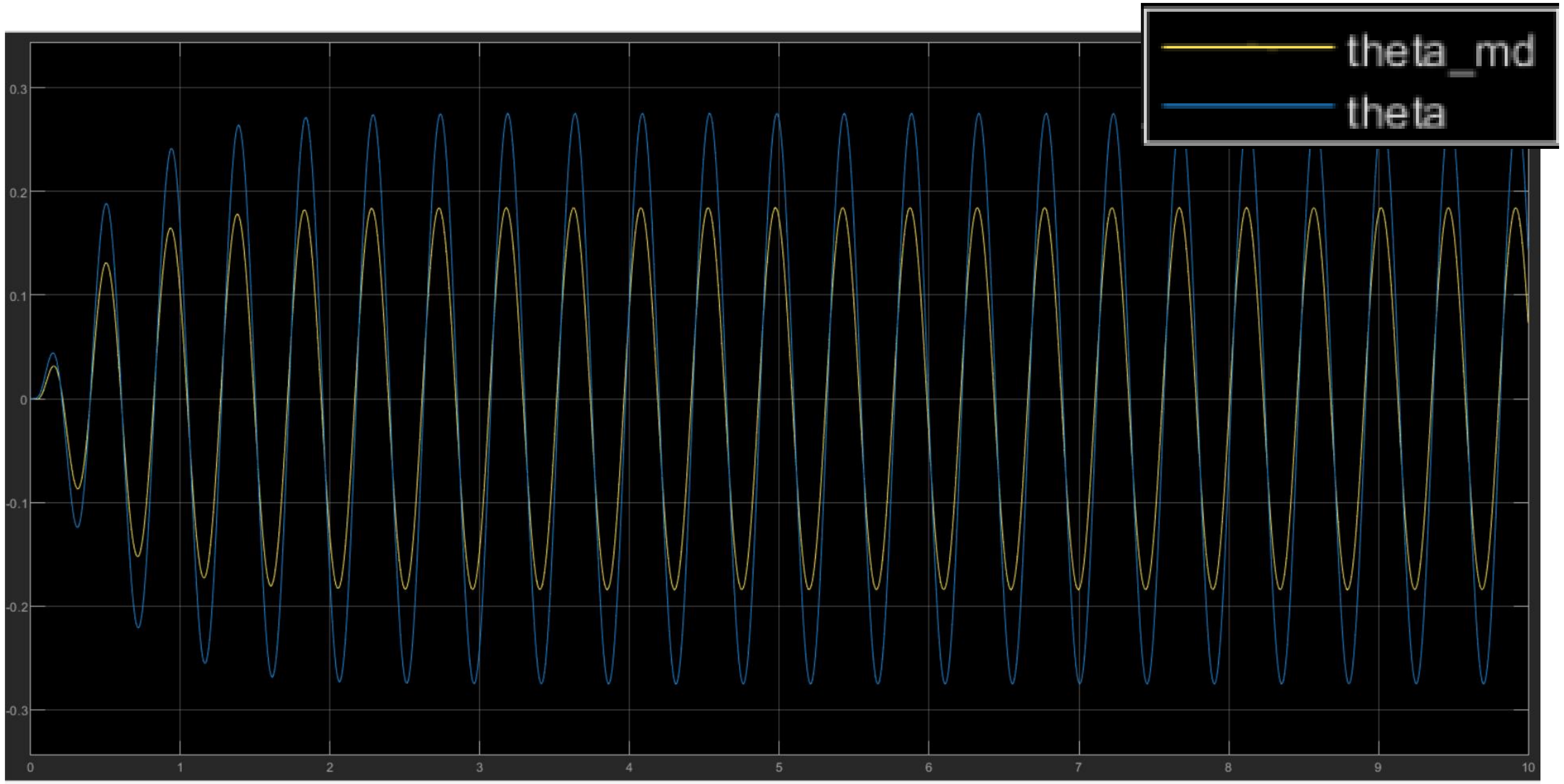
```
Damped Natural Frequencies (rad/s):
  365.4438
  248.1517
   95.6587
   62.8427
   13.9791
   13.9791
   22.4966
   22.4966
```

Natural_Frequency.m

```matlab
clc;clear;close all;
ms = 798; Is = 819; mu1 = 12; mu2 = 12;
l1 = 1.6; l2 = 1.5;
cs1 = 4000; cs2 = 5000;
ks1 = 110000; ks2 = 120000; ku1 = 200000; ku2 = 200000;
% Define the matrices
% [M] matrix
M_matrix = [ms 0 0 0;
    0 Is 0 0;
    0 0 mu1 0
    0 0 0 mu2];
% [C] matrix
C = [cs1+cs2 -l1*cs1+l2*cs2 -cs1 -cs2;
    -l1*cs1+l2*cs2 l1^2*cs1+l2^2*cs2 l1*cs1 -l2*cs2;
    -cs1 l1*cs1 cs1 0;
    -cs2 -l2*cs2 0 cs2];
% [K] matrix
K = [ks1+ks2 -l1*ks1+l2*ks2 -ks1 -ks2;
    -l1*ks1+l2*ks2 l1^2*ks1+l2^2*ks2 l1*ks1 -l2*ks2;
    -ks1 l1*ks1 ks1+ku1 0;
    -ks2 -l2*ks2 0 ks2+ku2];

% State-space formulation
A = [zeros(size(M_matrix)), eye(size(M_matrix));
     -M_matrix\K, -M_matrix\C];
eigenvalues = eig(A); % Complex eigenvalues

% Extract damped natural frequencies and damping ratios
damped_natural_frequencies = abs(eigenvalues); % Magnitude of eigenvalues

% Display results
disp('Damped Natural Frequencies (rad/s):');
disp(damped_natural_frequencies);
```

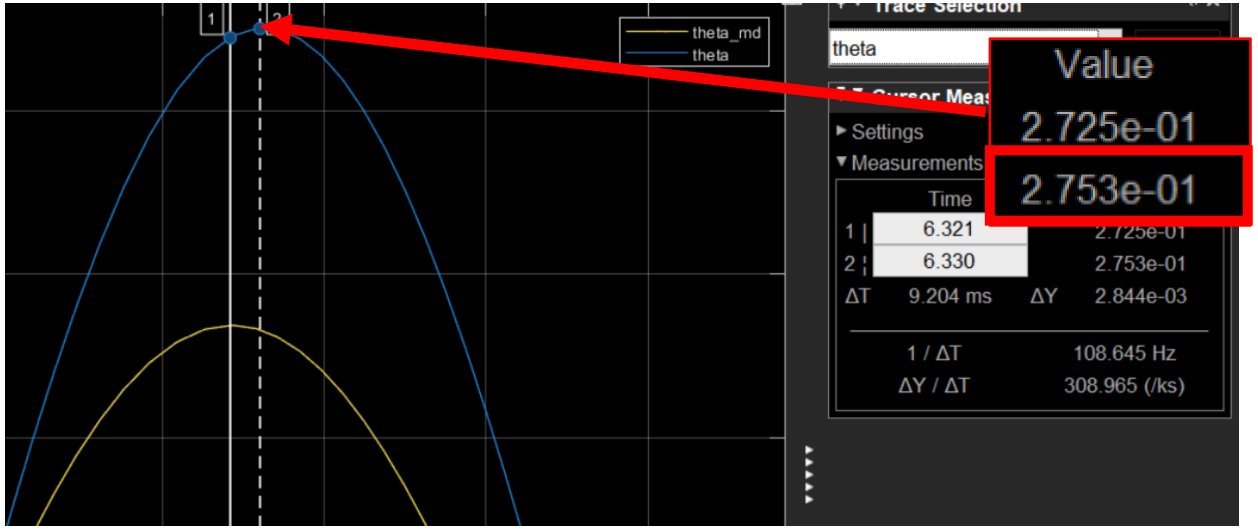
3 Mass Damper



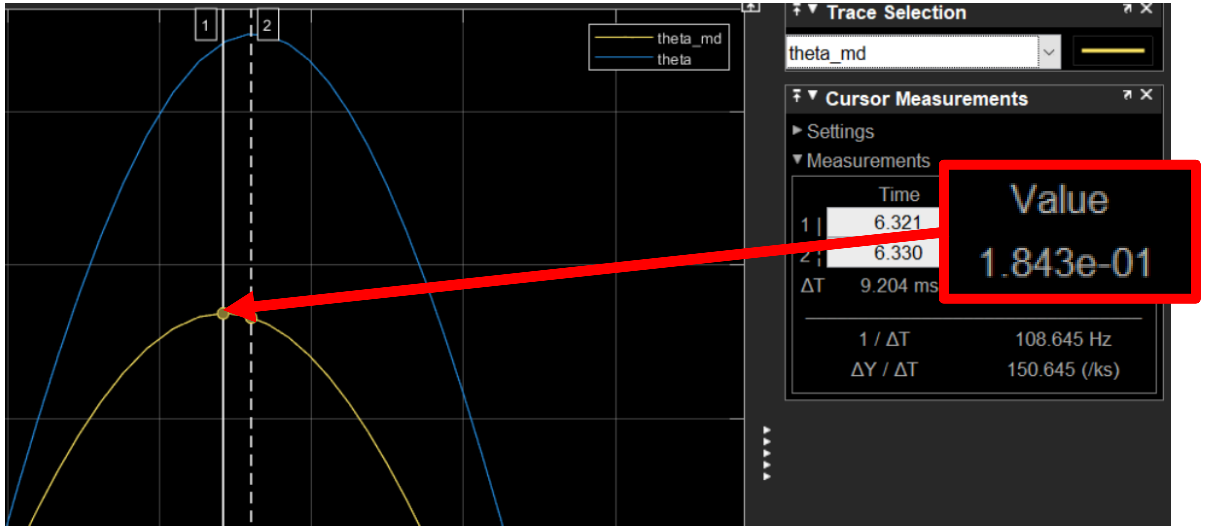


공진 주파수 ω = **13.9797 rad/sec**에서 **mass damper**에 의해 ***진폭이 감소함***을 볼 수 있다

3 Mass Damper



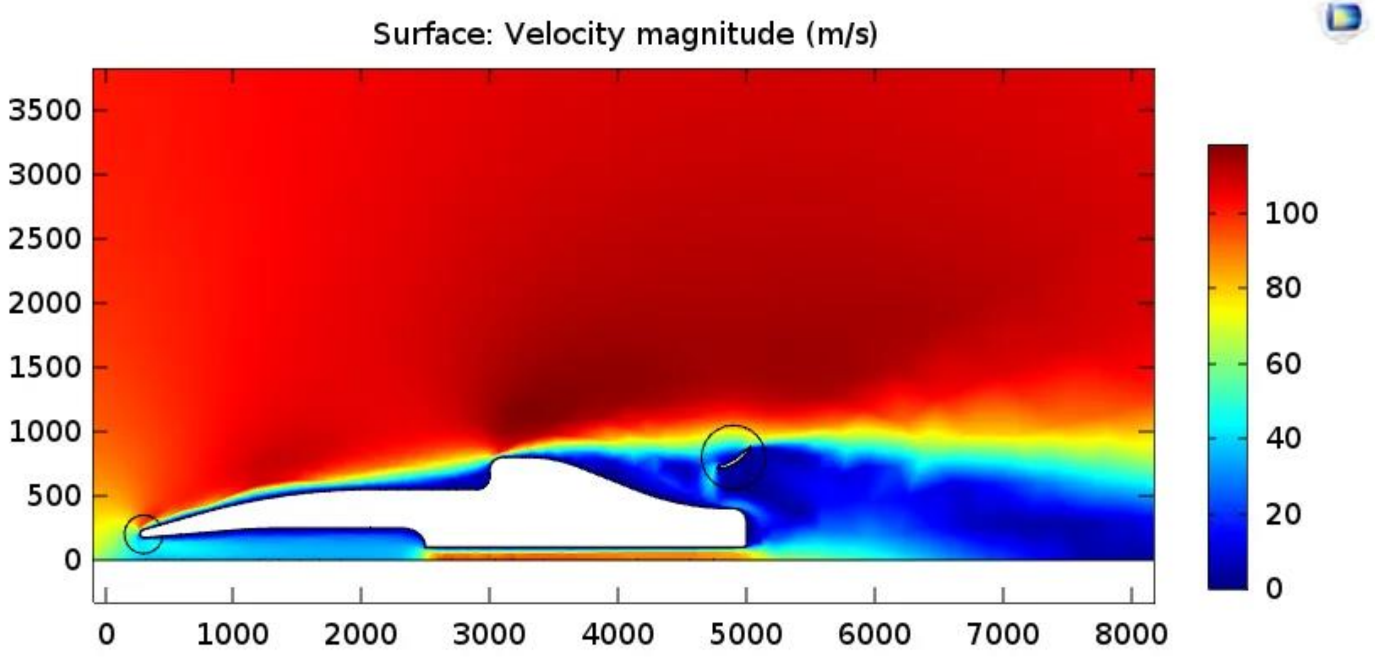
Mass damper가 없는 모델의 진폭: **0.2753 °**



Mass damper가 있는 모델의 진폭: **0.1843 °**

➔ 약 **0.1°** 의 차이

➔ 비슷한 범위에서 차체의 **pitch**가 응력에 미치는 영향 분석

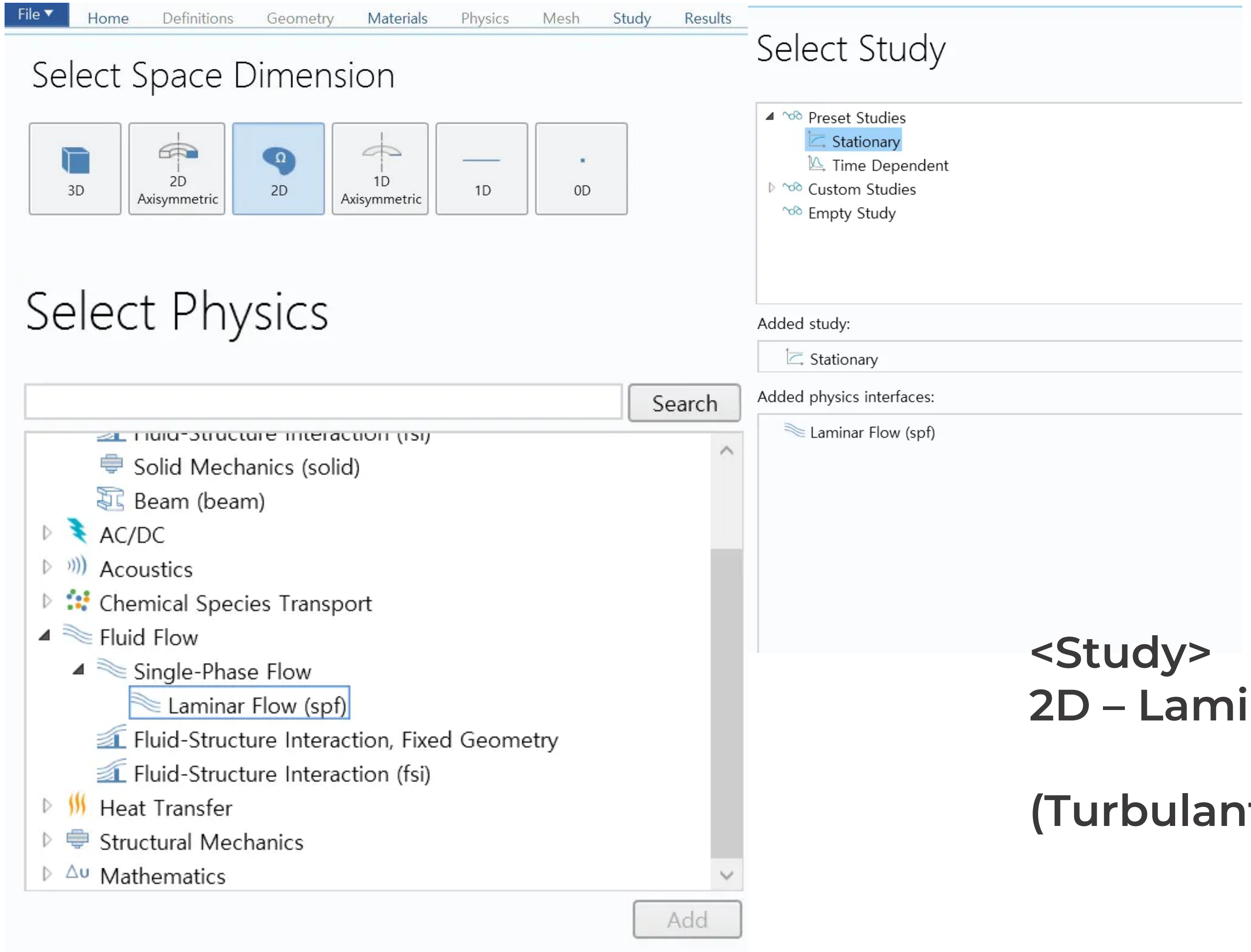


4

Aero Dynamics

고작 0.1° 보정을 위해 복잡한 장치들이 필요했을까?

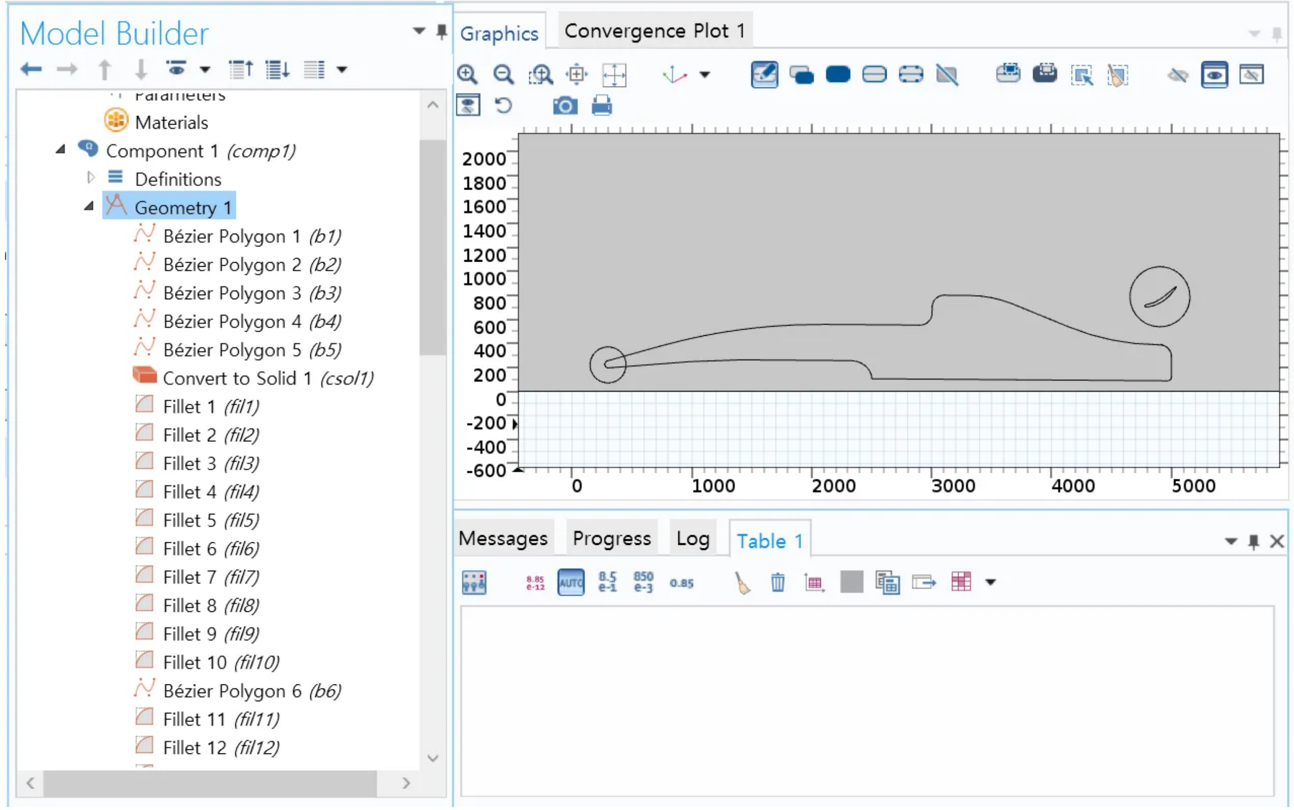
4 Aero Dynamics – Comsol Settings



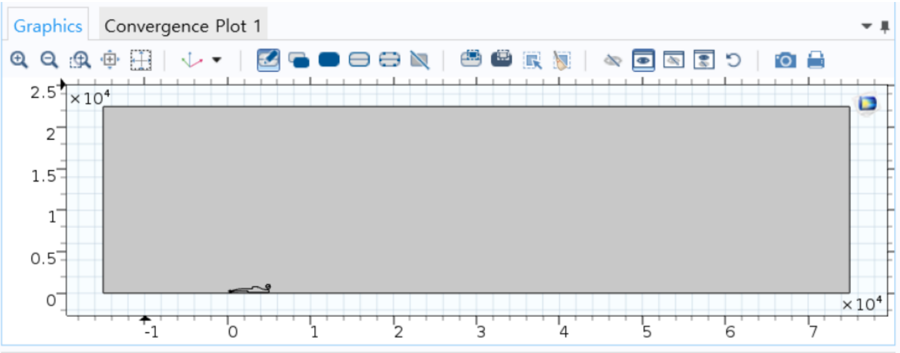
<Study>
2D – Laminar Flow – Stationary

(Turbulant Flow는 License 제한)

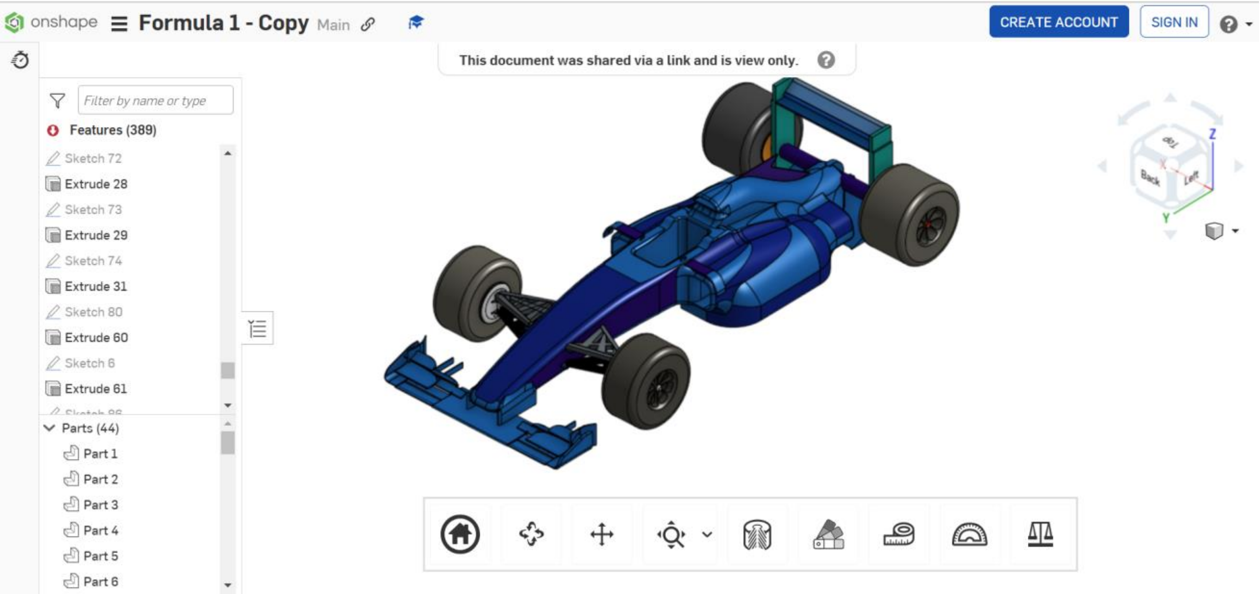
4 Aero Dynamics – Comsol Settings



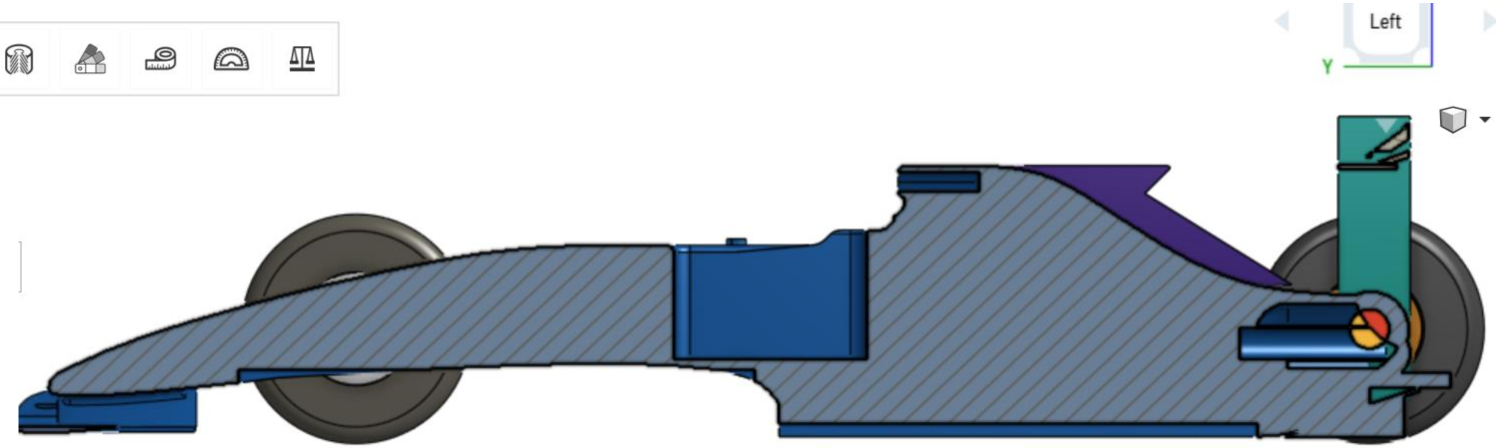
<Geometry>
Catia로 그린 dxf파일 import
➔ 형상이 너무 복잡해짐
➔ **COMSOL 상에서 그렸음**



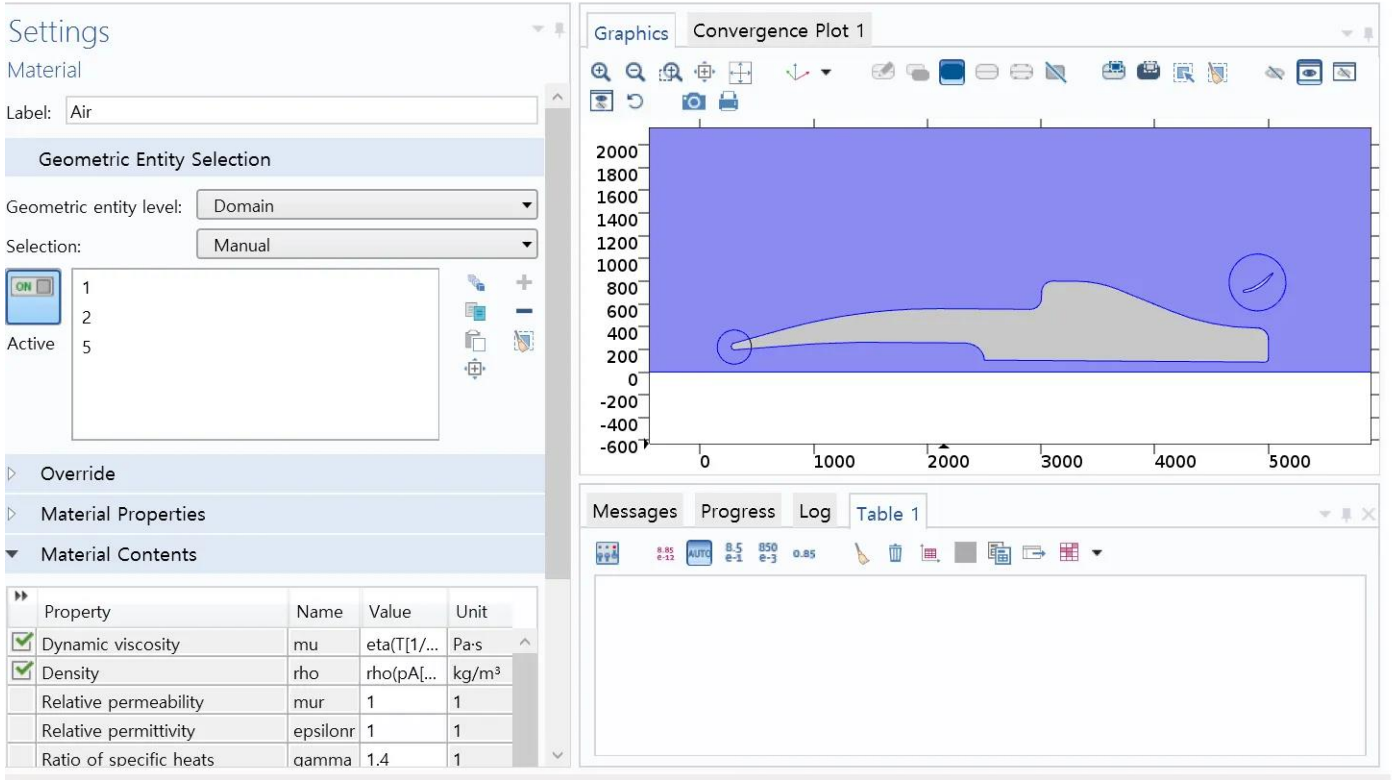
4 Aero Dynamics – Comsol Settings



Onshape 의 public source의 section view 를 참고하여 형성



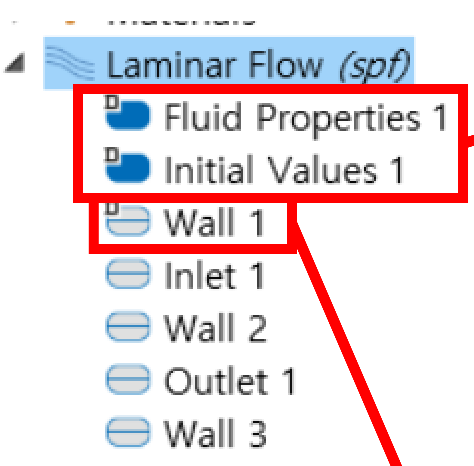
4 Aero Dynamics – Comsol Settings

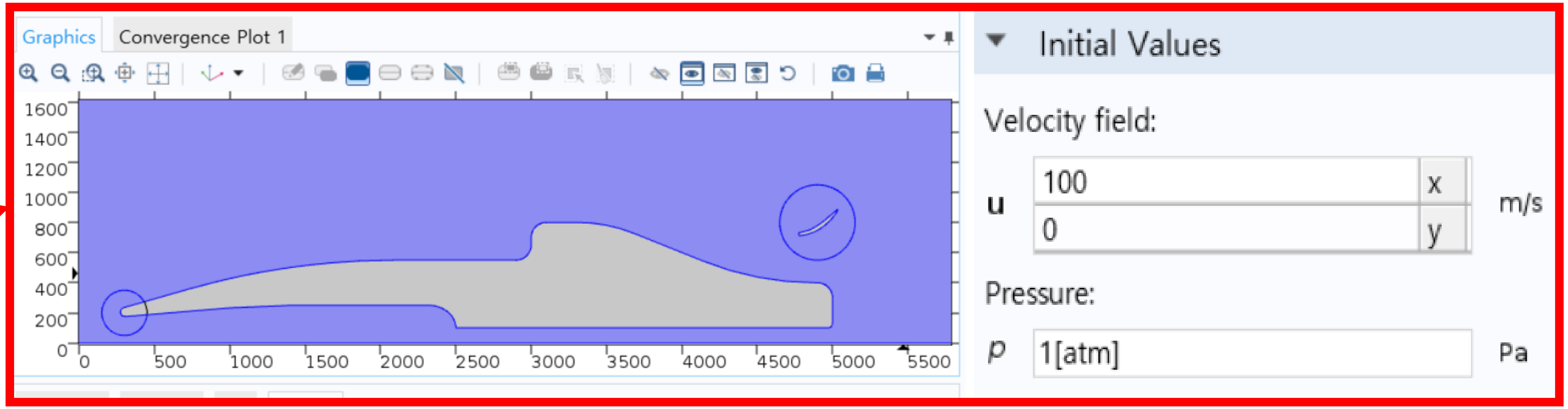


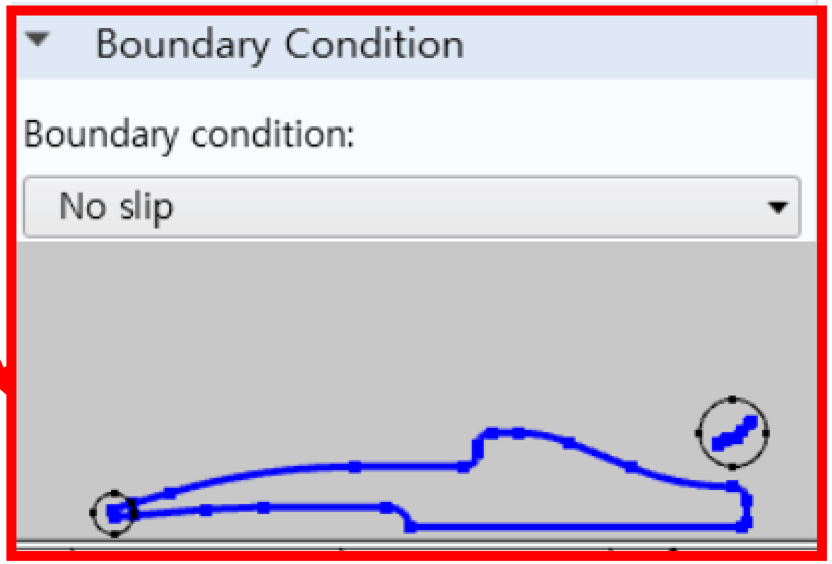
<Material>

COMSOL 내의 built-in material 중
Air 사용

4 Aero Dynamics – Comsol Settings

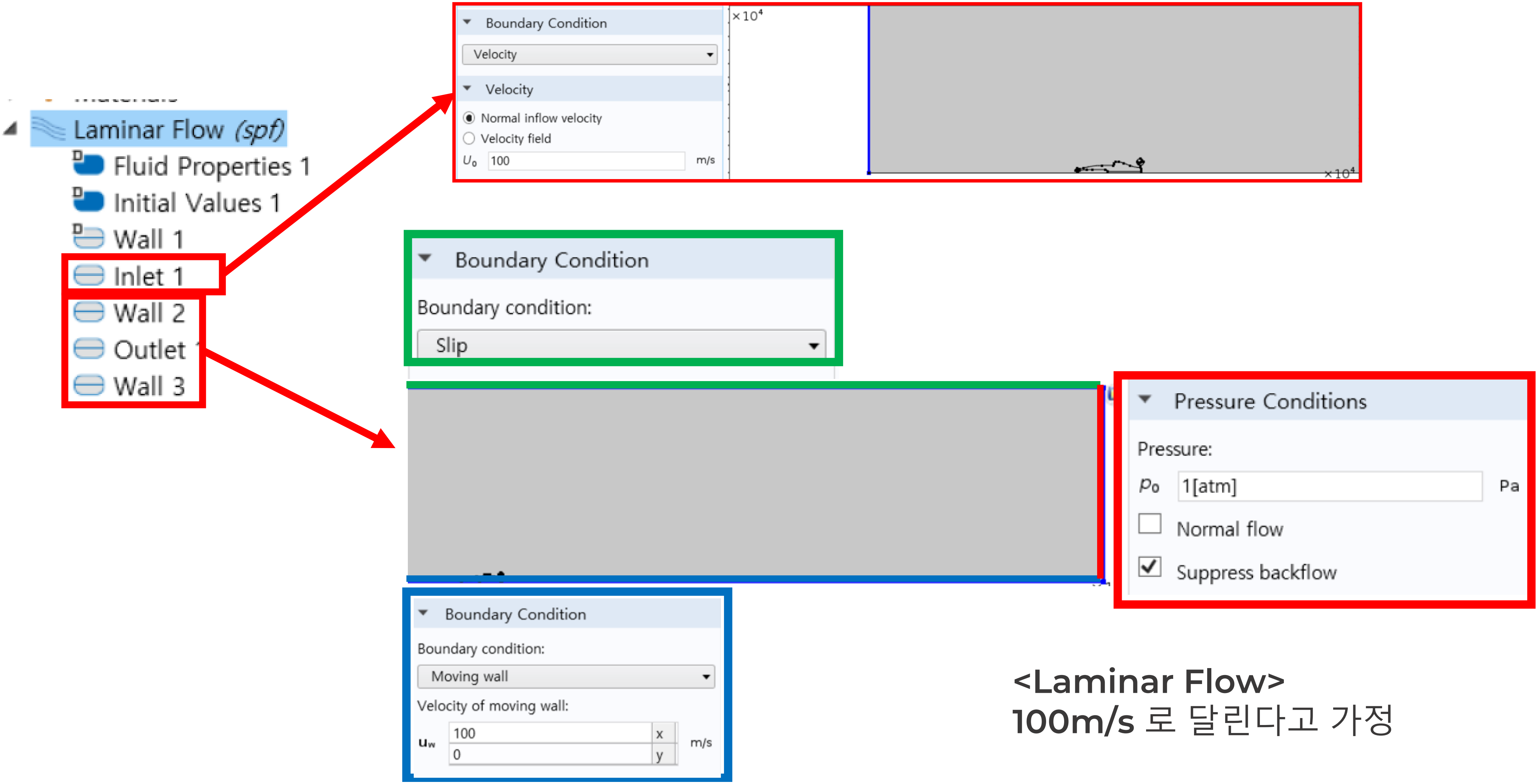






<Laminar Flow>
100m/s 로 달린다고 가정

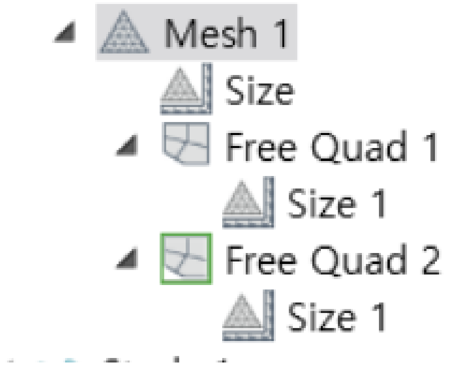
4 Aero Dynamics – Comsol Settings

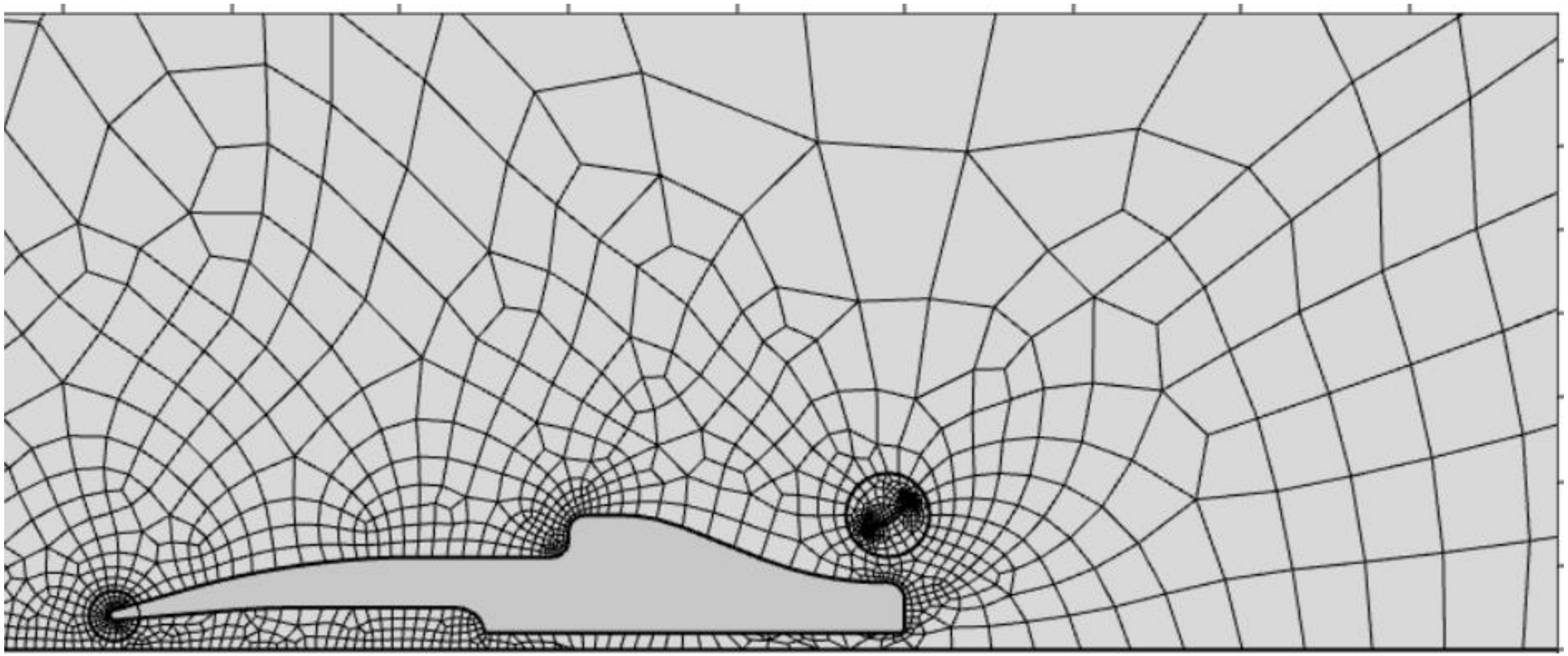


<Laminar Flow>
100m/s 로 달린다고 가정

4 Aero Dynamics – Comsol Settings

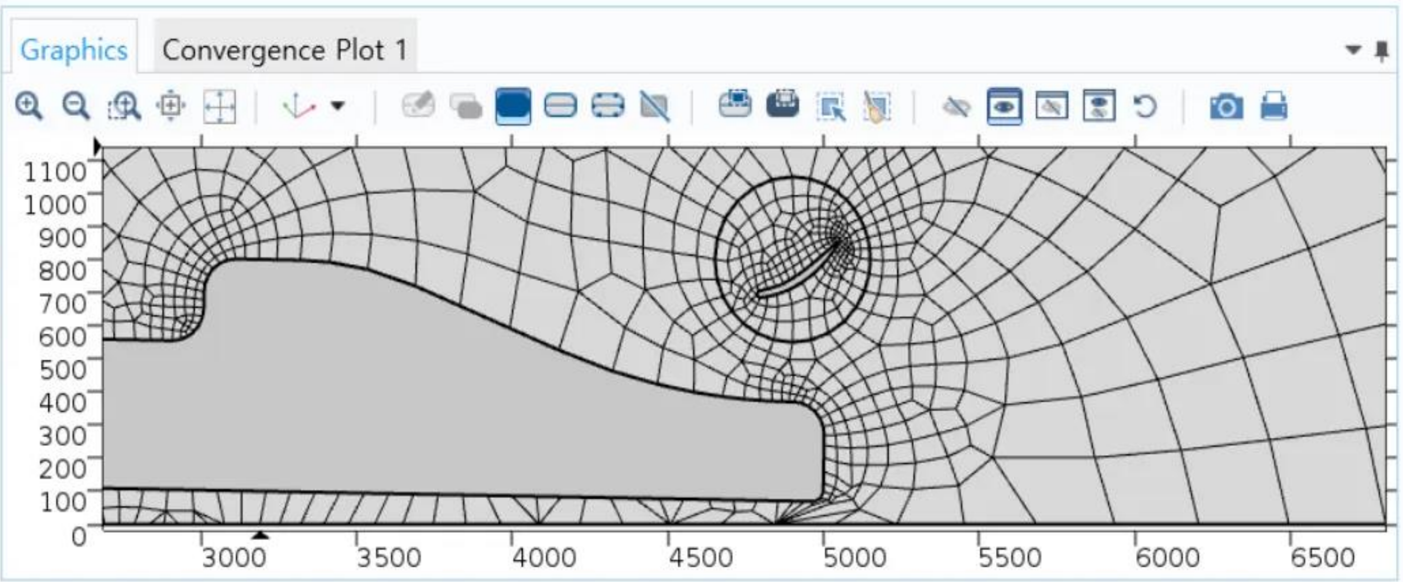
<Mesh>





4 Aero Dynamics – Comsol Settings

<Mesh>

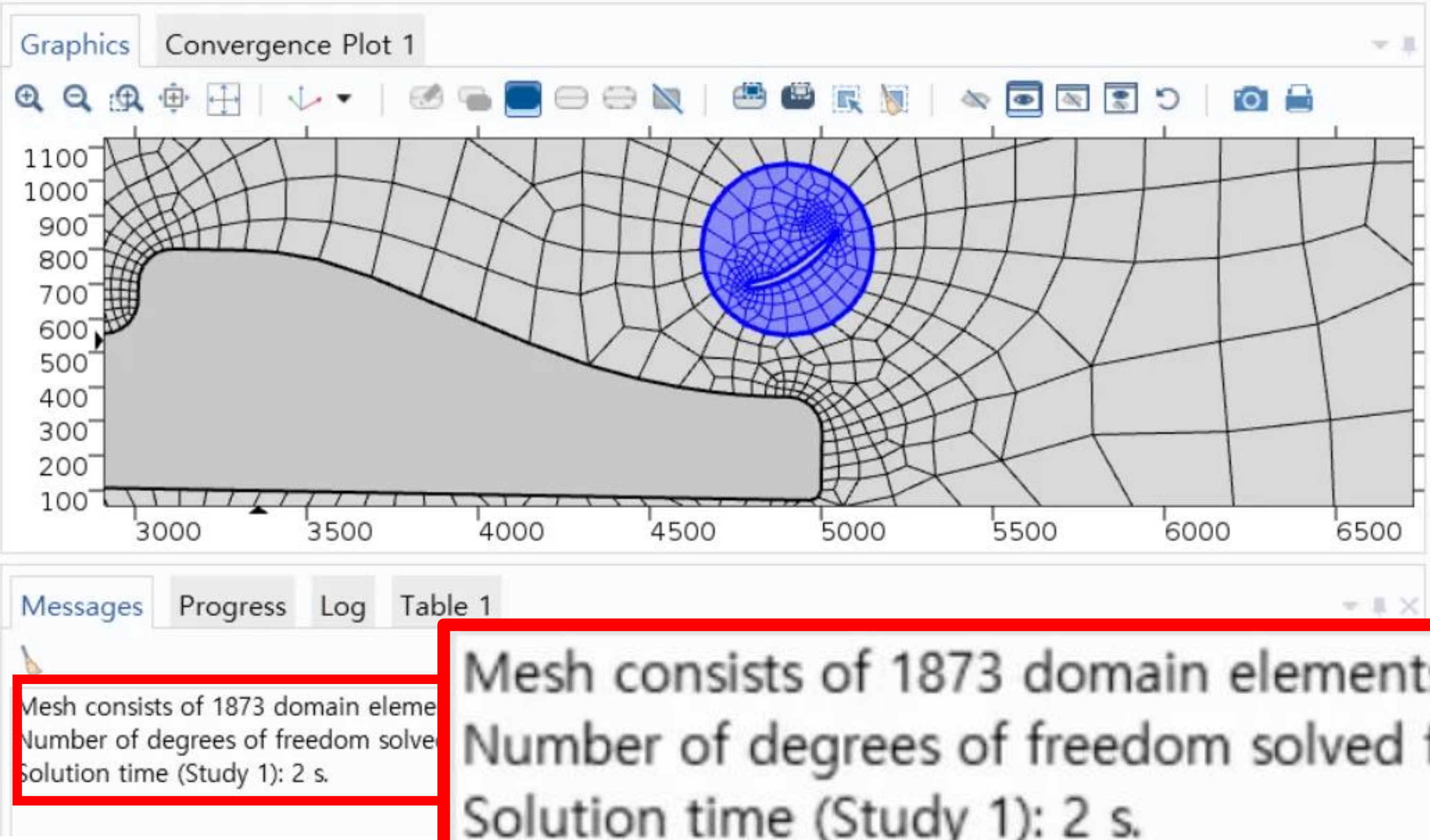


Messages | Progress | Log | Table 1

Mesh consists of 1715 domain elements and 432 boundary elements.
Number of degrees of freedom solved for: 5694.
Solution time (Study 1): 2 s.

4 Aero Dynamics – Comsol Settings

<Mesh>



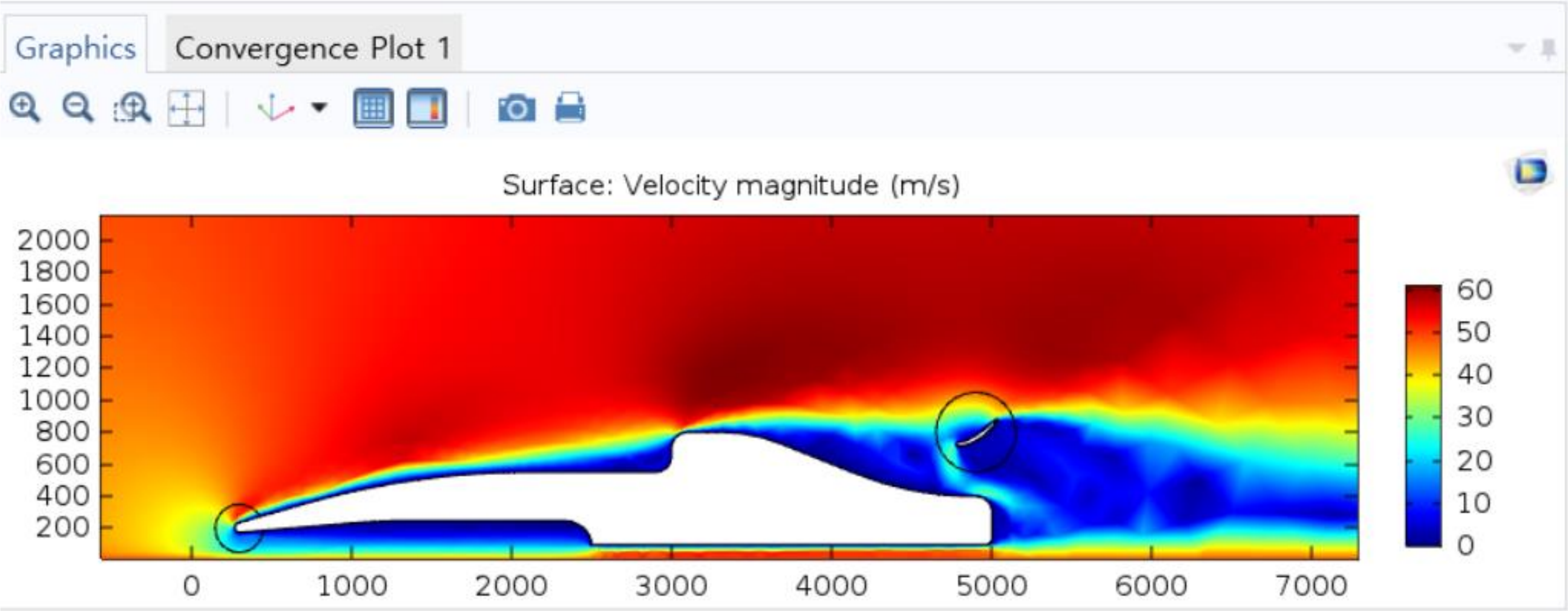
Mesh consists of 1873 domain elements and 442 boundary elements.
Number of degrees of freedom solved for: 6198.
Solution time (Study 1): 2 s.

<Mesh>

더 정확한 **downforce**의 계산을 위해 **rear wing** 부분의 **mesh**를 **finer**하게 설정

4 Aero Dynamics - Analysis

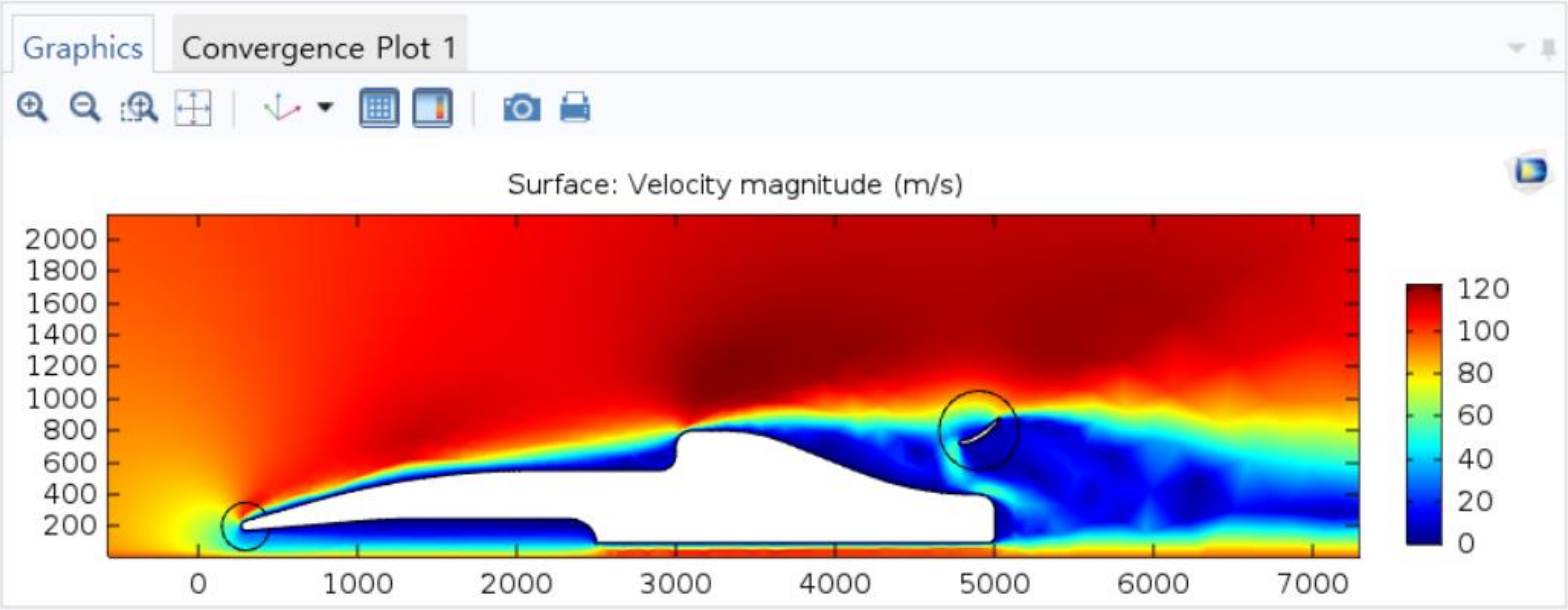
V = 50m/s



속도에 따라

4 Aero Dynamics - Analysis

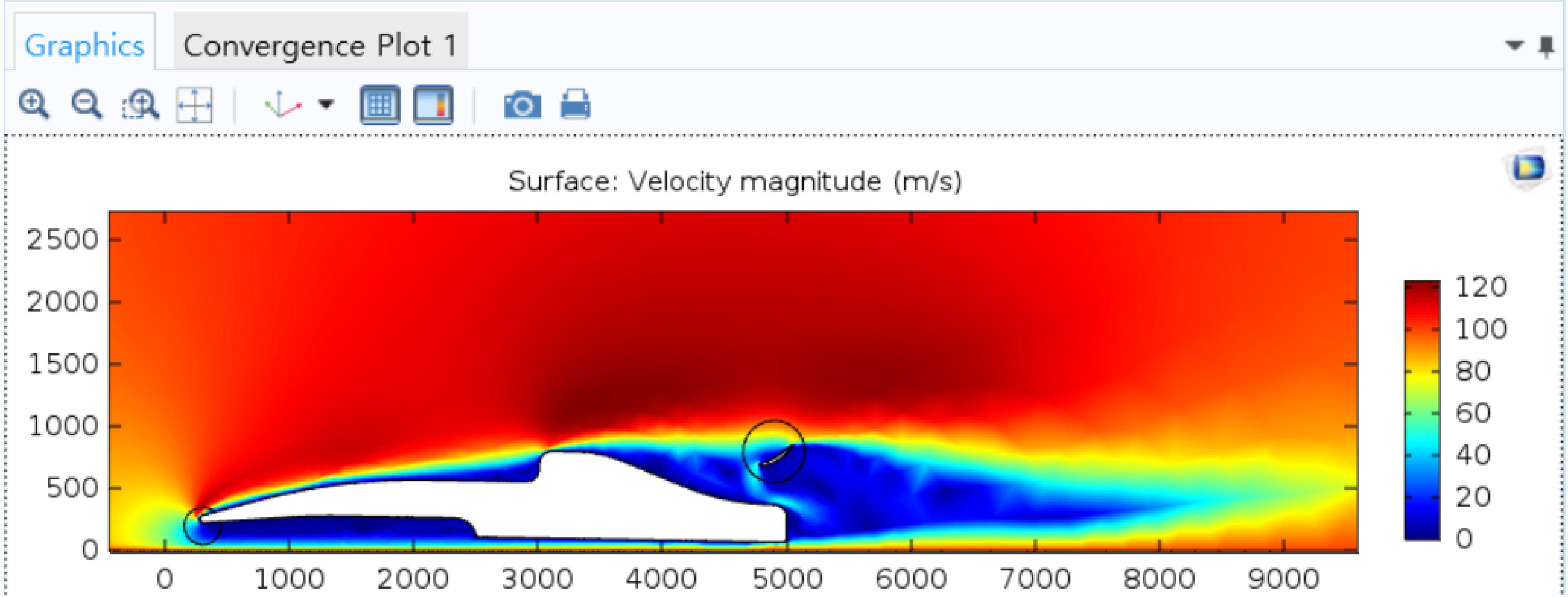
V = 100m/s



속도에 따라

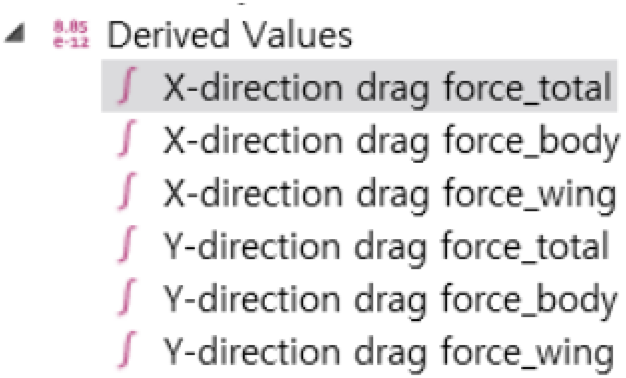
4 Aero Dynamics - Analysis

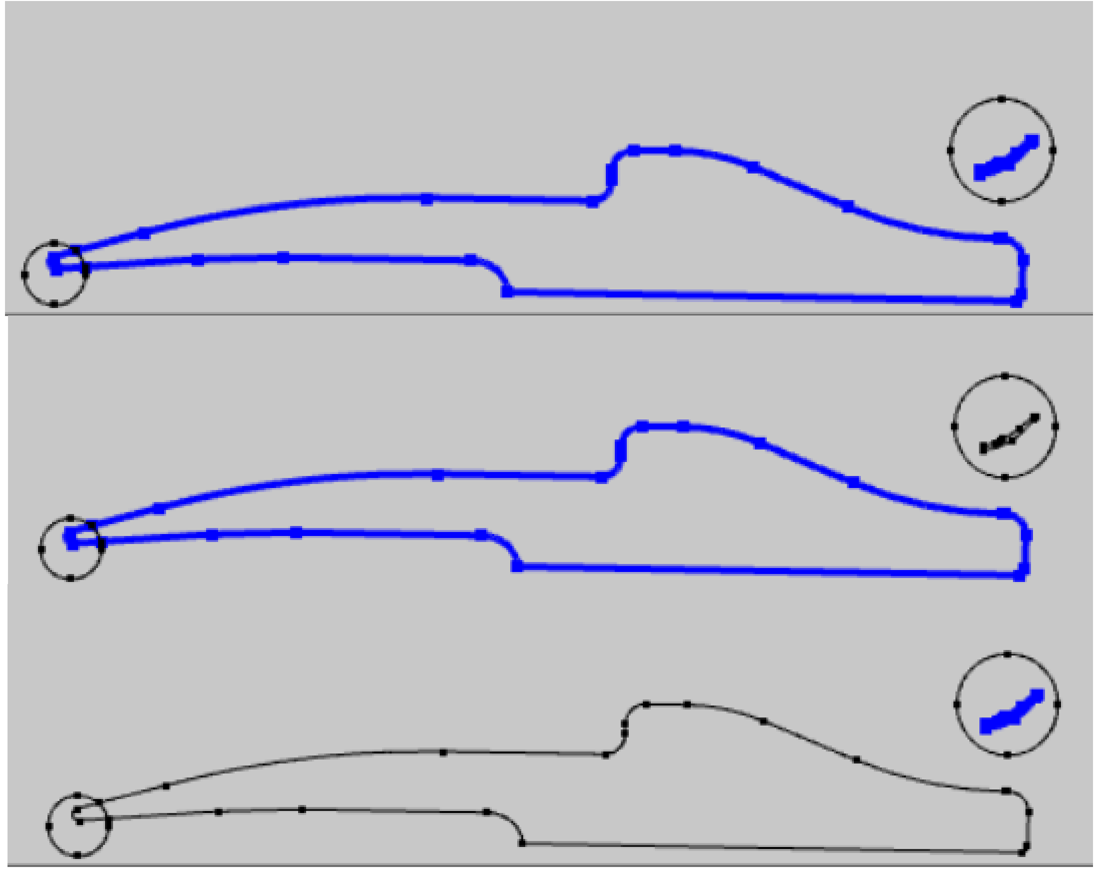
Pitch θ: -0.3° ~ 0.3 °



각도에 따라

4 Aero Dynamics - Analysis





<Total>

<Body>

<Wing>

4 Aero Dynamics - Analysis

Vehicle Speed (m/s)	Total Stress, x component(N/m)		Body Stress, x component (N/m)		Wing Stress, x component (N/m)		Total Stress, y component (N/m)		Body Stress, y component (N/m)		Wing Stress, y component (N/m)	
Pitch Angle(degree)	50	100	50	100	50	100	50	100	50	100	50	100
0	-835.49	-3341.8	-690.79	-2763	-144.7	-578.84	-4339.3	-17355	-4570.3	-18279	230.97	923.98
0.1°	-852.4	-3409.3	-691.52	-2765.8	-160.88	-643.51	-5665.4	-22661	-5922.2	-23688	256.79	1027.1
-0.1°	-836.33	-3378.8	-690.63	-2767.9	-145.7	-610.94	-7288.2	-32072	-7521.8	-33053	233.63	980.69
0.2°	-873.27	-3492.4	-705.61	-2821.1	-167.66	-671.29	-6464.5	-25864	-6729.5	-26925	265	1061.2
-0.2°	-844.76	-3378.8	-692.03	-2767.9	-152.73	-610.94	-8018.4	-32072	-8263.6	-33053	245.16	980.69
0.3°	-890.11	-3560.2	-732.89	-2931.3	-157.23	-628.87	-4229.2	-16915	-4476.4	-17904	247.23	988.88
-0.3°	-844.93	-3379.6	-697.25	-2788.9	-147.68	-590.71	-8292	-33167	-8531	-34123	239.07	956.28

4 Aero Dynamics - Analysis

Down force

Vehicle Speed (m/s)	Wing Stress, y component (N/m)	
Pitch Angle(degree)	50	100
0	230.97	923.98
0.1°	256.79	1027.1
-0.1°	233.63	980.69
0.2°	265	1061.2
-0.2°	245.16	980.69
0.3°	247.23	988.88
-0.3°	239.07	956.28

Downforce를 만드는 응력

1061.2-923.98 = 137.22 N/m

0.2° 차이 ➔ 12.94 % 차이

Drag force

Vehicle Speed (m/s)	Total Stress, x component(N/m)	
Pitch Angle(degree)	50	100
0	-835.49	-3341.8
0.1°	-852.4	-3409.3
-0.1°	-836.33	-3378.8
0.2°	-873.27	-3492.4
-0.2°	-844.76	-3378.8
0.3°	-890.11	-3560.2
-0.3°	-844.93	-3379.6

Dragforce를 만드는 응력

890.11-835.49 = 54.62 N/m

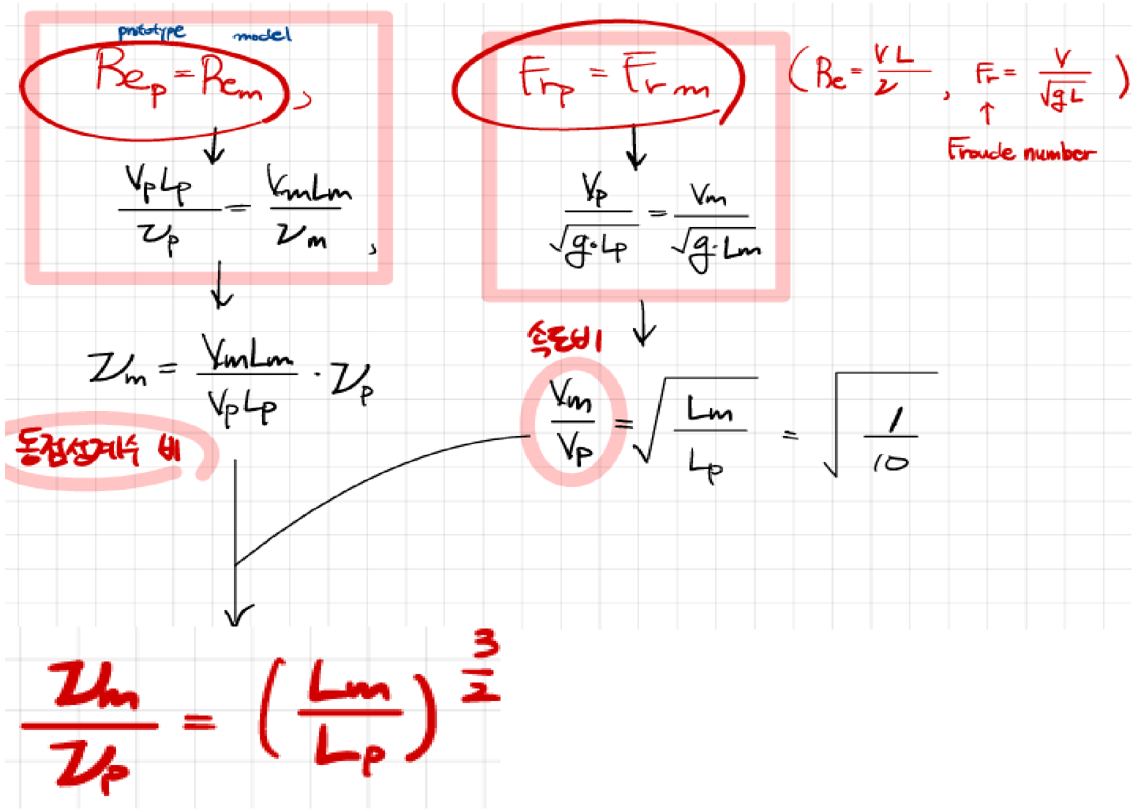
0.3° 차이 ➔ 6.13 % 차이

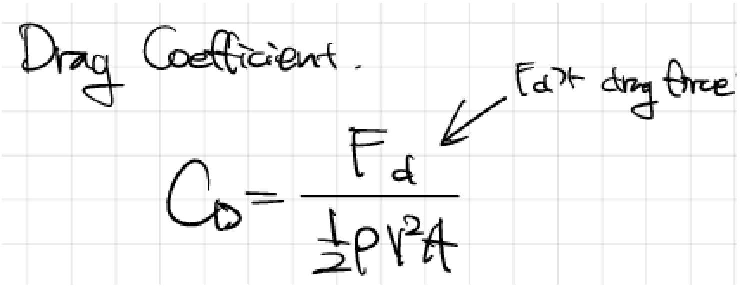
4 Aero Dynamics   Scale Modeling???

Scale Modeling 시도 : 1/10 모델 활용으로 연산량 ↓ 시도

“Renolds number, Froude number 같게 하는 dynamic viscosity를 설정한다면

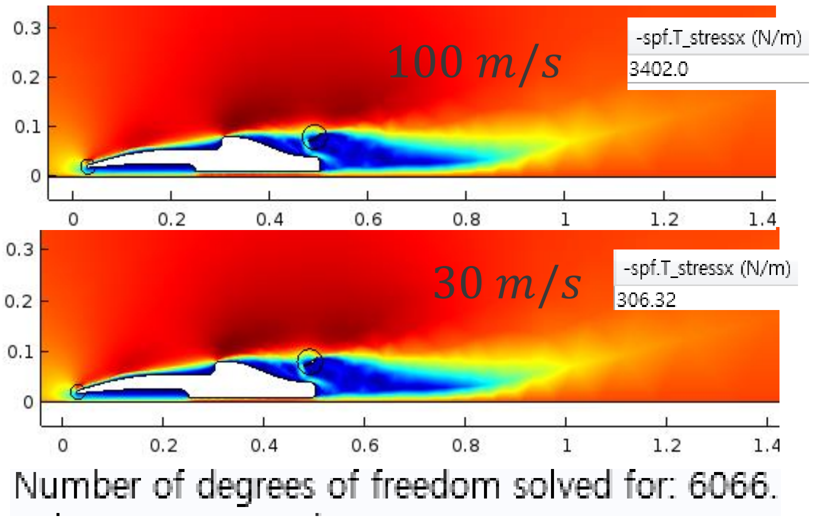
1/n배로 scale된 모델에서도 같은 Cd값을 활용할 수 있게 된다” ➔연산량을 획기적으로 줄일 수 있을 것으로 기대.





4 Aero Dynamics

Scale Modeling???



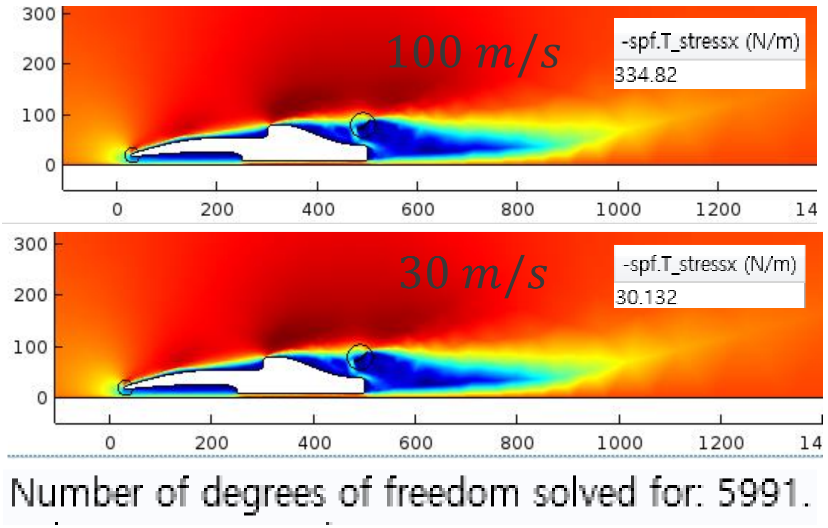
1/10 size로 scale modeling :

dynamic viscousity : $(\frac{1}{10})^{1.5} = \frac{1}{31.62}$배

➔ 결과 Cd는 동일

$Scale : \frac{1}{10}$

$Dynamic\ Viscosity: \left(\frac{L_{model}}{L_{prototype}}\right)^{1.5} = \left(\frac{1}{10}\right)^{1.5} = \frac{1}{31.62}$



	Original Model	1/10 Model
	$DOF = 6066$	$DOF = 5991$
100 m/s	$F_D = 3402.0\ N/s$	$F_D = 334.82\ N/s$
30 m/s	$F_D = 306.32\ N/s$	$F_D = 30.132\ N/s$

$F_d = C_d \frac{1}{2}\rho A v^2$ 이므로, **F/length** 는 **1/10**배가 되어야 함. → 높은 정확도를 보임

그러나 **Mesh**수와 연산시간에 큰 변화가 없어 사용할 이유를 보여주지 못함

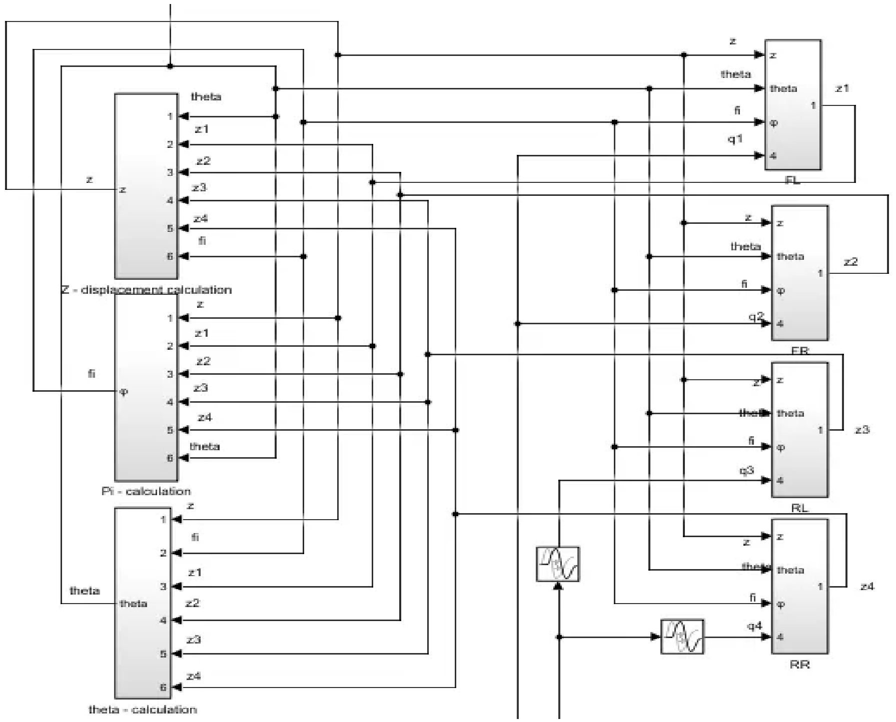
4 Aero Dynamics

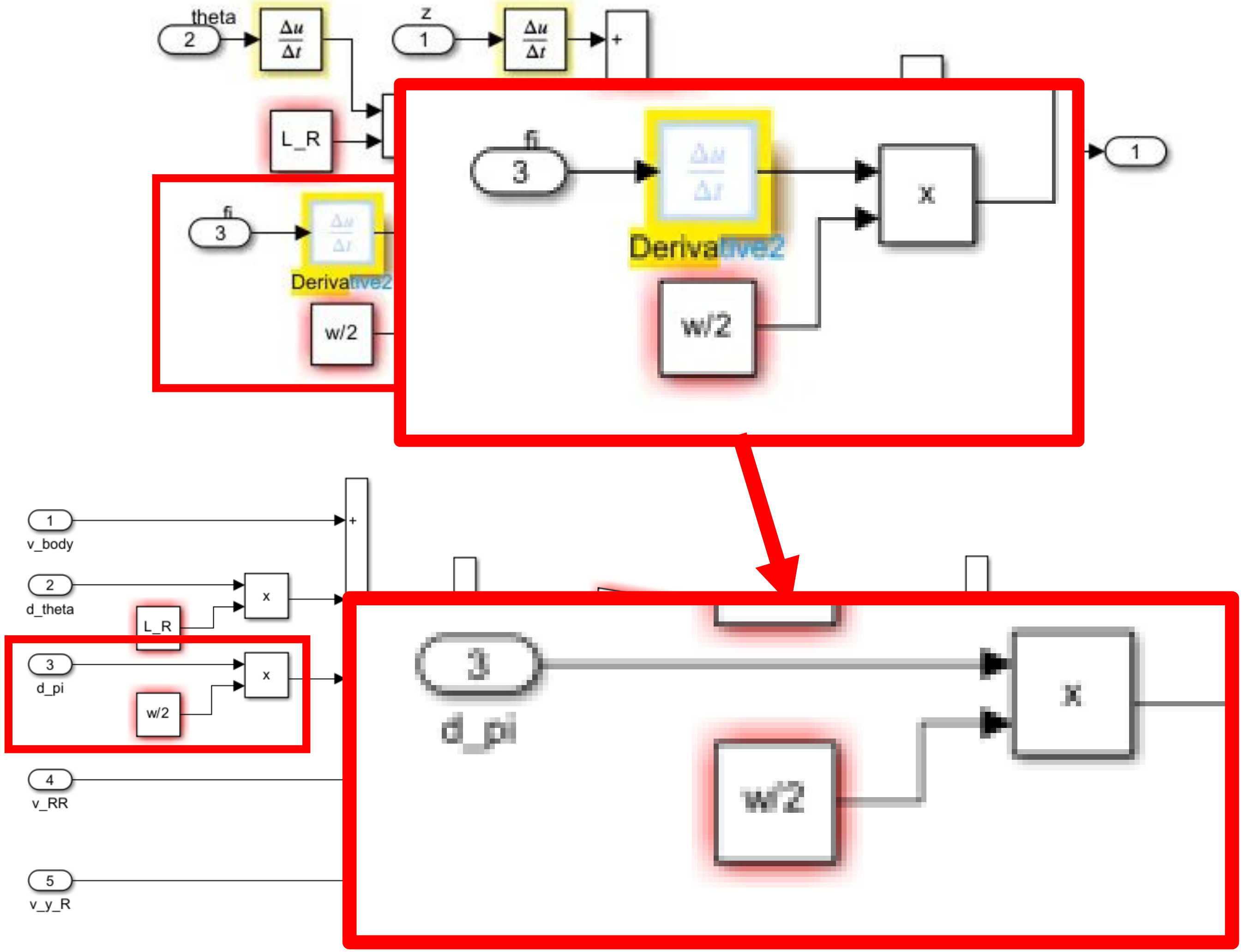
~~Scale Modeling???~~

5

Difficulties & Reflections

5 Difficulties & Reflections – 미분기→적분기



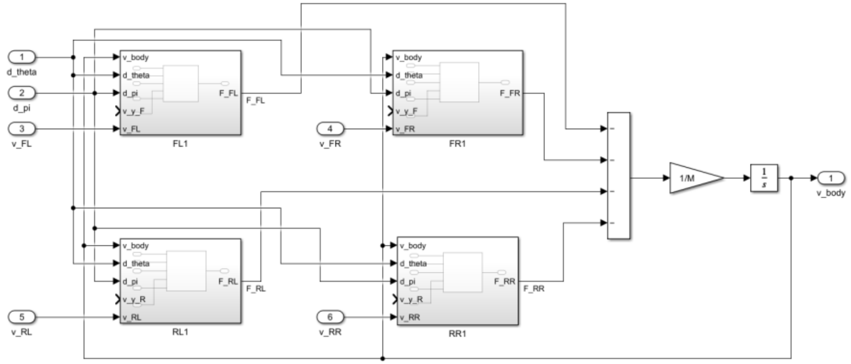


논문대로 변위 기준의 모델링(미분기 포함)

➔ 속도 기반의 모델링(적분기 포함, 미분기 제거)

5 Difficulties & Reflections – 대수 루프

Q) 왜 외부의 서스펜션 (FL, FR, RL, RR)값을 그대로 사용하지 않고 내부에서 subsystem을 또다시 구현했는가?



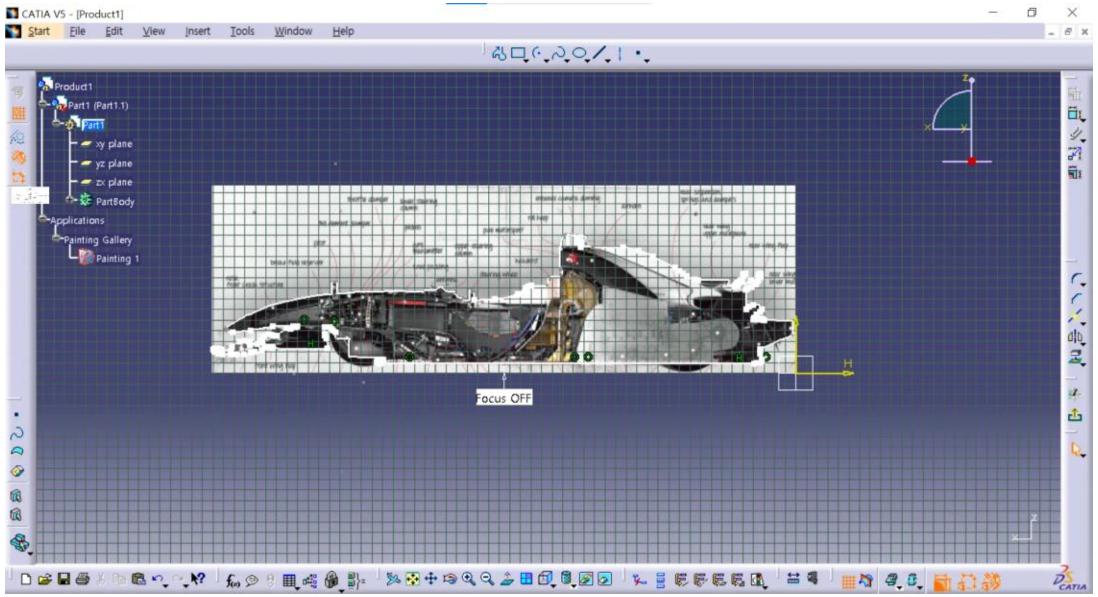
3. 대수 루프 주의 사항

입력과 출력에 동일한 변수를 사용할 때는 **대수 루프**가 발생할 가능성이 큽니다. 대수 루프는 다음과 같은 문제를 일으킬 수 있습니다:

- 시스템의 상태나 변수가 **순환적인 의존성**을 가질 때, Simulink는 이를 해결할 방법을 찾지 못할 수 있습니다.
- 대수 루프를 해결하기 위해 Simulink는 특정 해결 방법을 사용하지만, 때때로 **수치적으로 불안정**할 수 있고, 이로 인해 **시뮬레이션이 제대로 실행되지 않을 수 있습니다**.

한 Subsystem의
input에 있는 변수를 output으로도 출력한다면
(즉 output 값을 그대로 다시 input으로 사용한다면)
순환적인 의존성으로 인해 수치적 불안정

5 Difficulties & Reflections – 2D 형상 모델링



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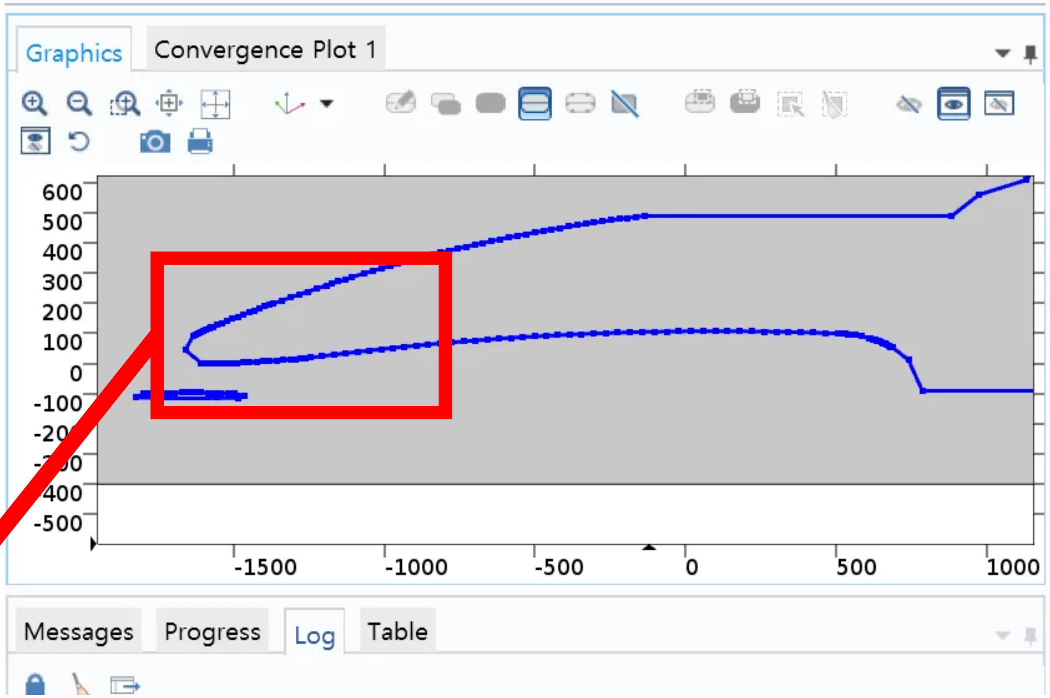
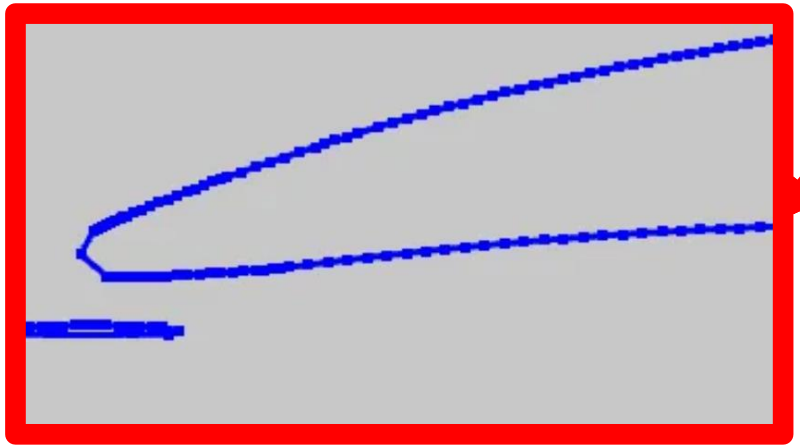
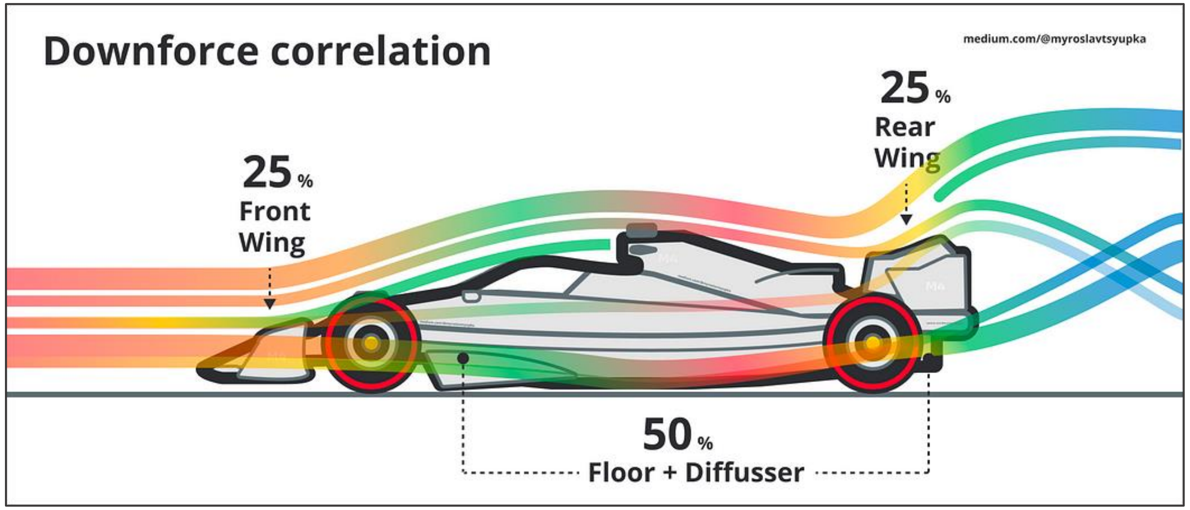
Import





<COMSOL>

5 Difficulties & Reflections – COMSOL 결과의 타당성



Vehicle Speed (m/s)	Total Stress, x component(N/m)		Wing Stress, y component (N/m)	
Pitch Angle(degree)	50	100	[illegible]	[illegible]
0	-835.49	-3341.8	230.97	923.98
0.1°	-852.4	-3409.3	256.79	1027.1
-0.1°	-836.33	-3378.8	233.63	980.69
0.2°	-873.27	-3492.4	265	1061.2
-0.2°	-844.76	-3378.8	245.16	980.69
0.3°	-890.11	-3560.2	247.23	988.88
-0.3°	-844.93	-3379.6	239.07	956.28

X2

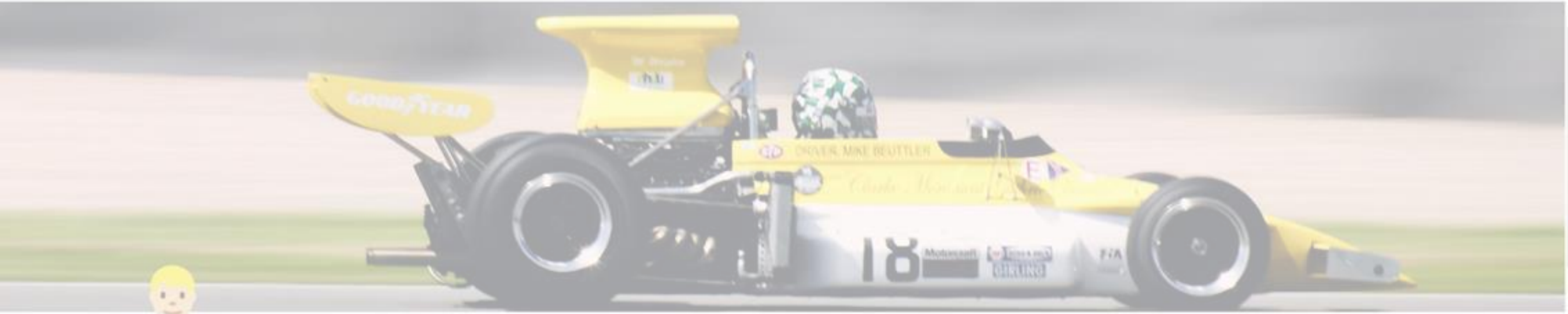
X4

$$downforce = \frac{1}{2\rho} A C_l v^2$$

5 Difficulties & Reflections – etc.

- 타이어와 로드 간의 마찰계수와 차량 가속도 간의 관계를 구해 가속, 감속에 의한 **pitch** 현상을 동역학적으로 분석해보려 했으나 실패

- **F1**차량처럼 고속으로 움직이는 물체에 대해서는 **laminar flow**가 아니라 **turbulent flow**가 더 적합
  → **COMSOL** 기능에 제한이 있어서 더 정확한 시뮬레이션 불가



CAE TEAM PROJECT

F1 BANNED TECHNOLOGY

2020044466 이호연
2022091285 김지원
2020029107 송이찬

> CAE : Computer Aided Engineering
>
> HYU Department of Automotive Engineering
>
> Prof. Seungjae Min
>
> Protected: CAE_2024
>
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>
> https://cdl.hanyang.ac.kr/education/aue3028-2024/

Full-body Model (14 dof vehicle model)
Full-body Model (14 dof vehicle model)

FRICS(Front to Rear Interconnected Suspension)
FRICS(Front to Rear Interconnected Suspension)

Aerodynamics
Aerodynamics

매스 댐퍼(Tuned mass damper)
매스 댐퍼(Tuned mass damper)

~~DAS(Dual Axis Steering)~~
DAS(Dual Axis Steering)

감사합니다

PROJECT NOTION

https://substantial-workshop-80b.notion.site/CAE-TEAM-PROJECT-5b6961eb4be743d2af1c7c0254bc6c77