

Spoiler

CFD를 통한 Spoiler 실험과 제어

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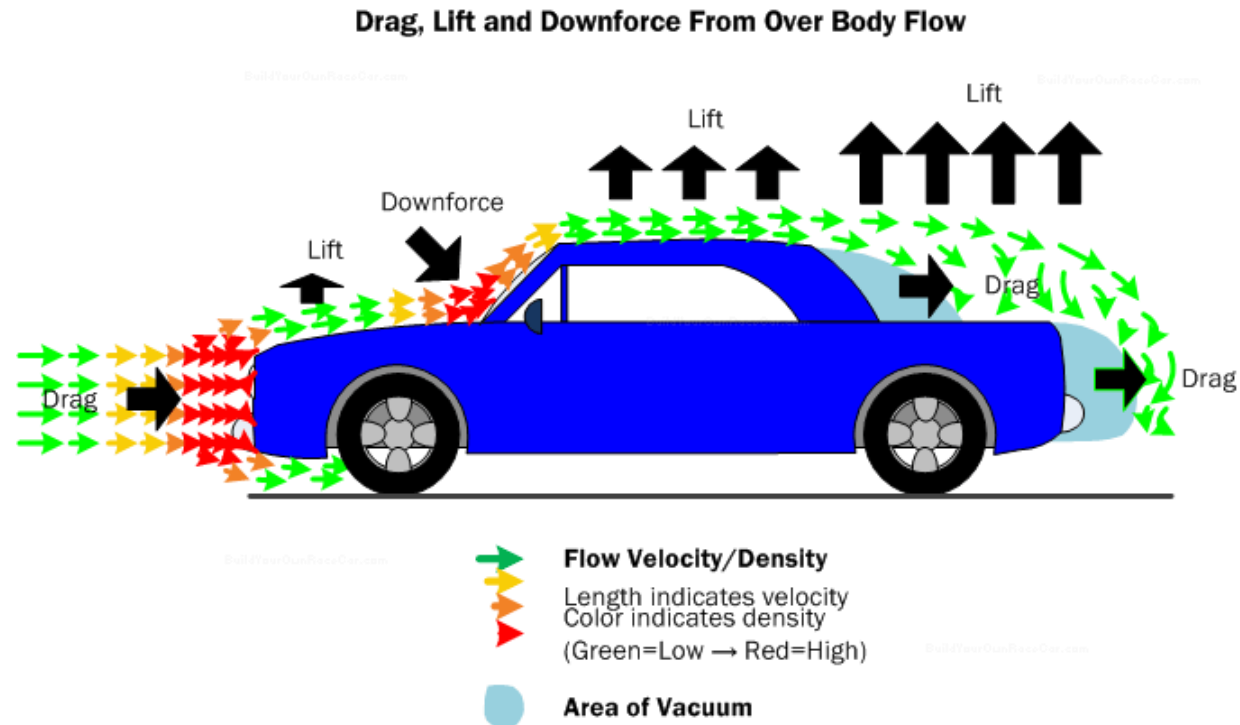
주제 및 팀명 선정



이론

자동차에 작용하는 힘

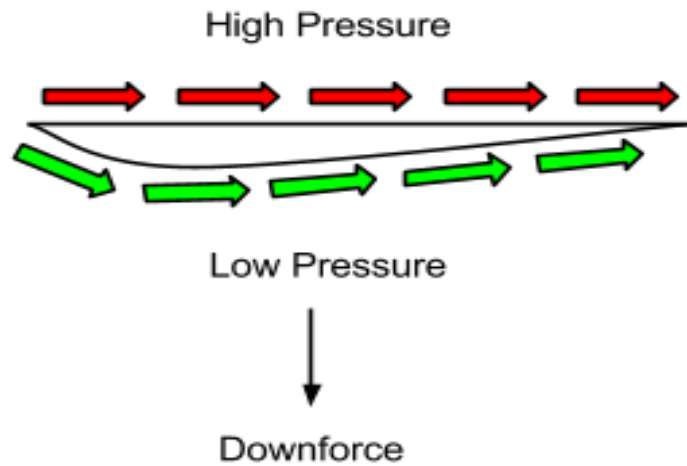
자동차에 작용하는 유체에 의한 힘



이론

Spoiler의 이해

- High velocity air flow
- Low velocity air flow



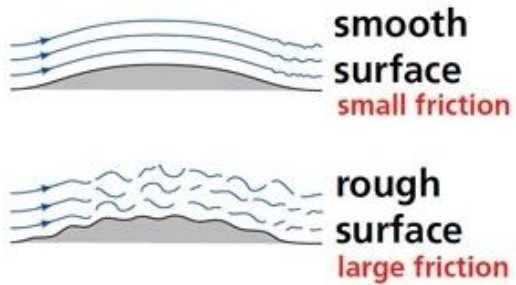
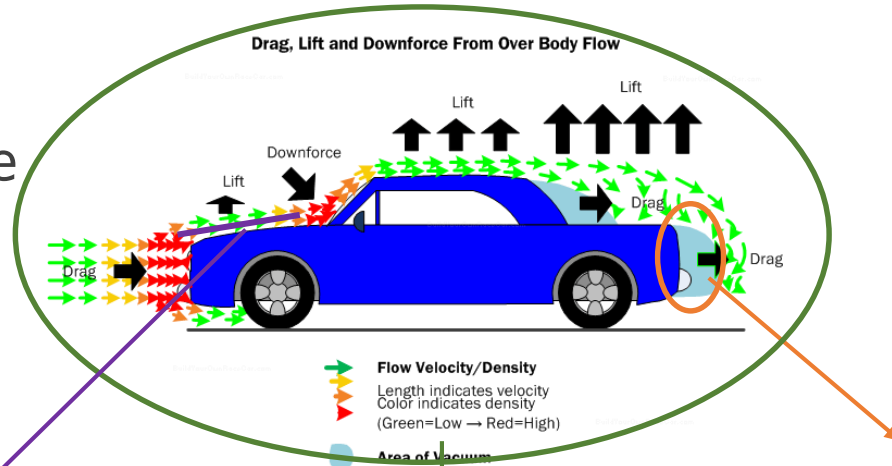
$$\underbrace{\left(\frac{1}{2} \rho v^2\right)}_{\text{kinetic energy}} + \underbrace{(\rho g z)}_{\text{work done by weight}} + \underbrace{(p)}_{\text{work done by pressure}} = \text{constant}$$

Bernoulli Equation

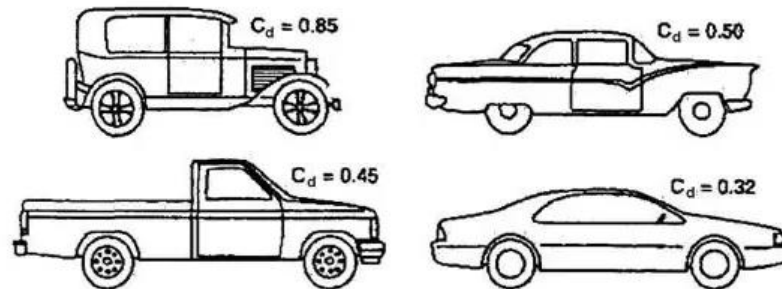
이론

Spoiler의 이해

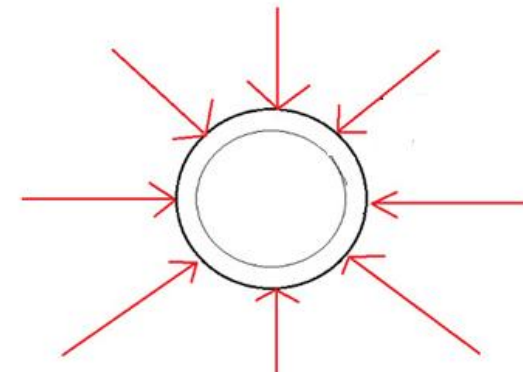
Drag Force



friction



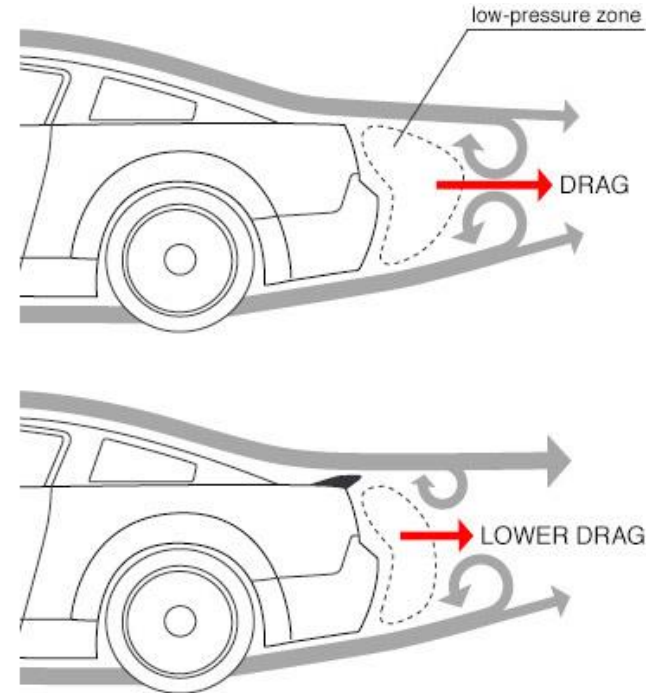
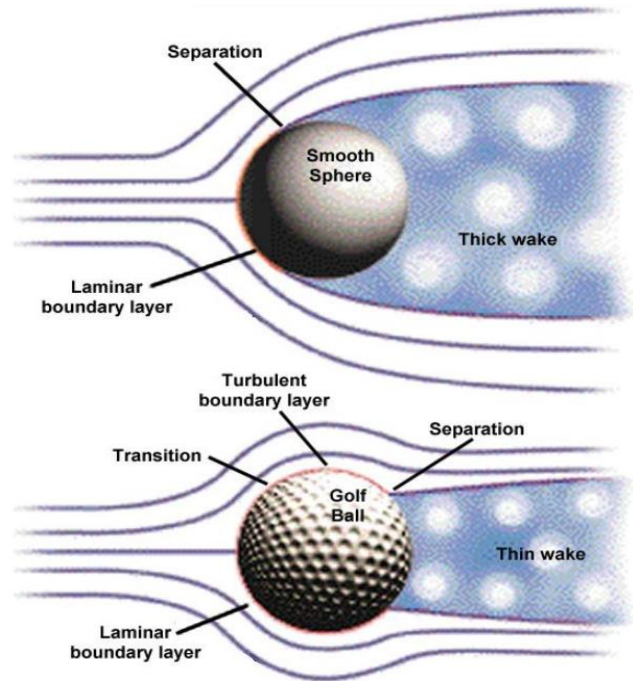
shape



이론

Spoiler의 이해

$$F = \rho * A * v^2 * \frac{c_d}{2} \quad (F=\text{drag force, } C_d:\text{ drag coeffiency})$$



이론

Spoiler의 이해

Newtonian Fluid Reynolds Number (Re) Formula

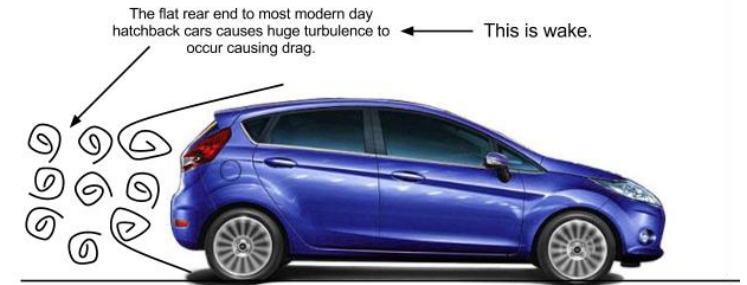
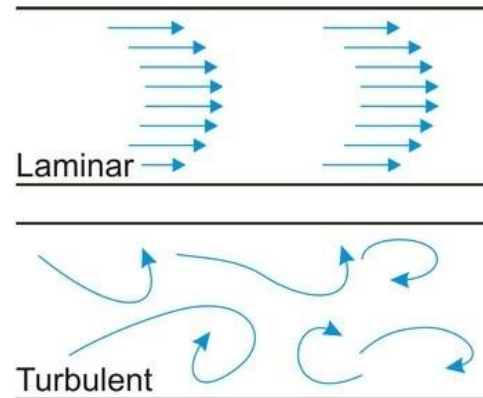
$$Re = \frac{\rho V D}{\mu}$$

μ – fluid dynamic viscosity in $kg/(m \cdot s)$

ρ – fluid density in kg/m^3

V – fluid velocity in m/s

D – pipe diameter in m



평판에서의 Re

$Re < 5 \times 10^5$ Laminar

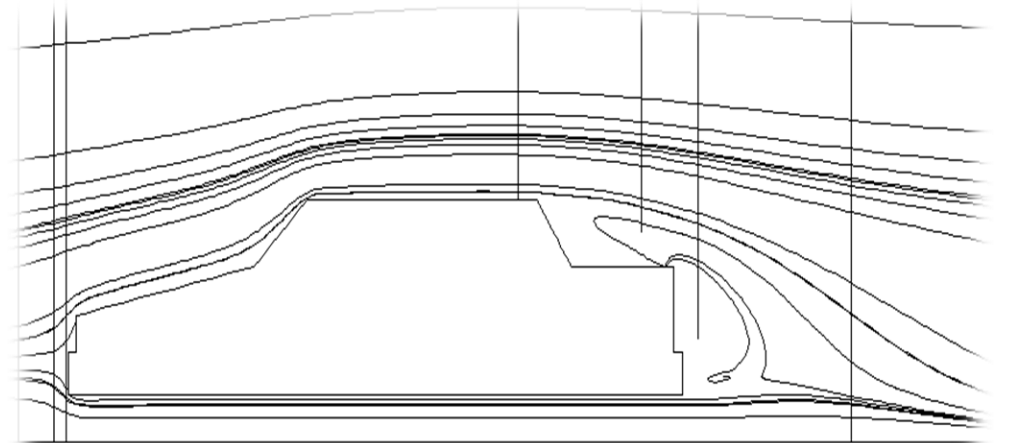
$Re > 5 \times 10^5$ Turbulent

Spoiler Aerodynamic Properties – 1

Reality



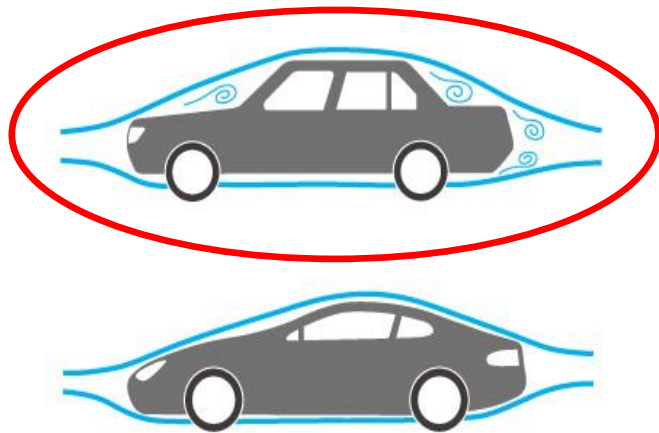
Comsol



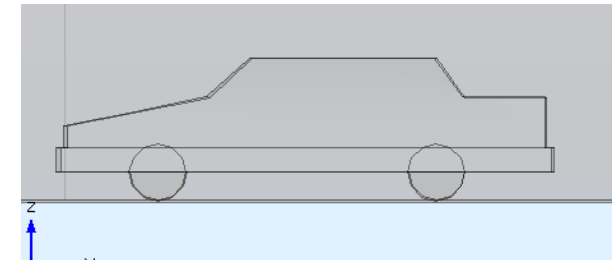
1. Fluid model

$$Re = \frac{\rho * V * L}{\mu} = \frac{1.2 * 40 * 1.35}{1.515 * 10^{-5}} = 2.14 * 10^6 \quad (5 * 10^5) \rightarrow \textit{Turbulent}$$

2. Car Model

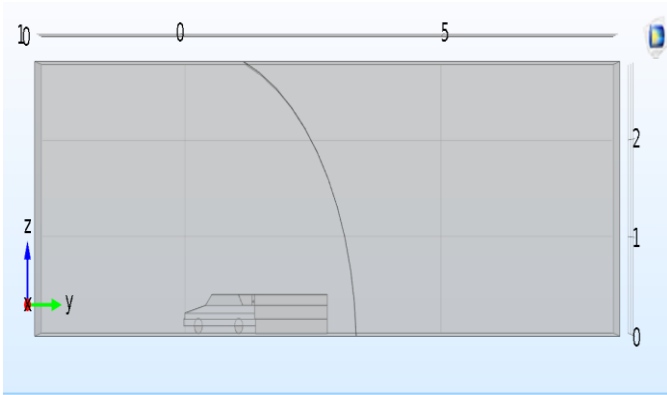


Volvo
740



1/10 model

3. Comsol Modeling



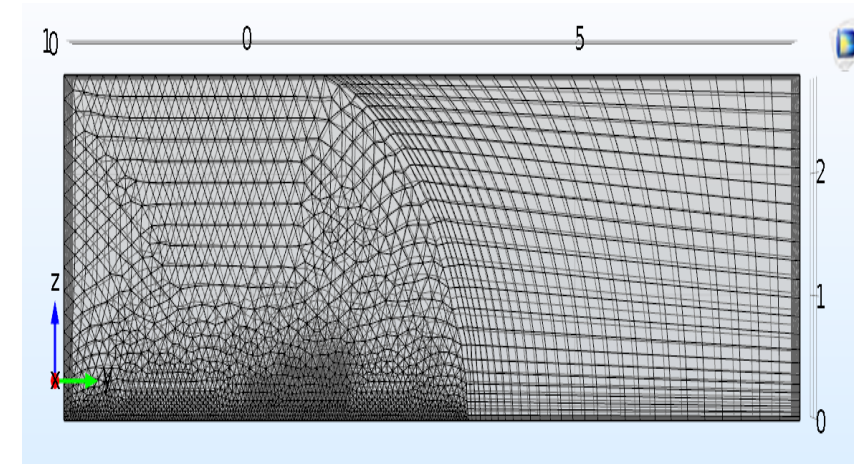
Mesh 크기의 차별화

+



Symmetry 이용

빠른 계산작업 & 높은 정확도



4. 결과 분석

◎ 현실값 : 0.42

◎

Total stress, y component (N)	Total stress, z component (N)
-37.962	-17.844

Drag Force : $F = \rho * A * v^2 * c_d / 2$

$$c_d = \frac{2 * F}{\rho * A * v^2} = \frac{2 * 37,962}{1.22 * 0.081 * 40^2} = 0.48$$










◎ 차체 모델링

◎ 풍동 실험의 k,ε 값의 차이

◎ Mesh의 한계성

Spoiler Aerodynamic Properties – 2

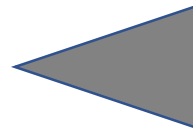
스포일러 Modeling

Shape		Drag Coefficient
Sphere	→ 	0.47
Half-sphere	→ 	0.42
Cone	→ 	0.50
Cube	→ 	1.05
Angled Cube	→ 	0.80
Long Cylinder	→ 	0.82
Short Cylinder	→ 	1.15
Streamlined Body	→ 	0.04
Streamlined Half-body	→ 	0.09

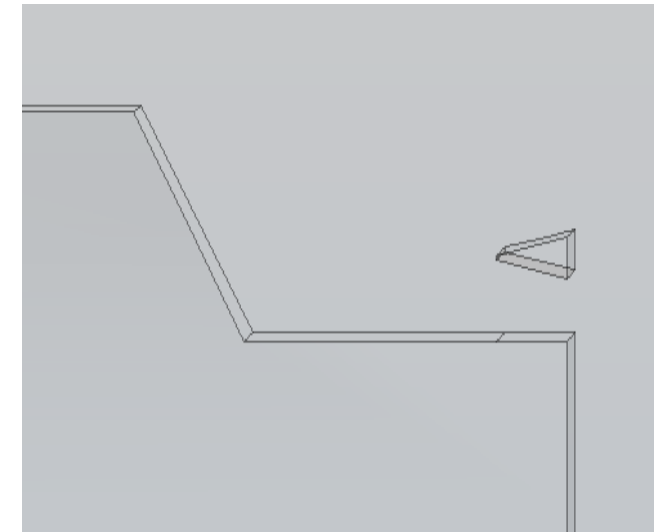
Measured Drag Coefficients



Cone

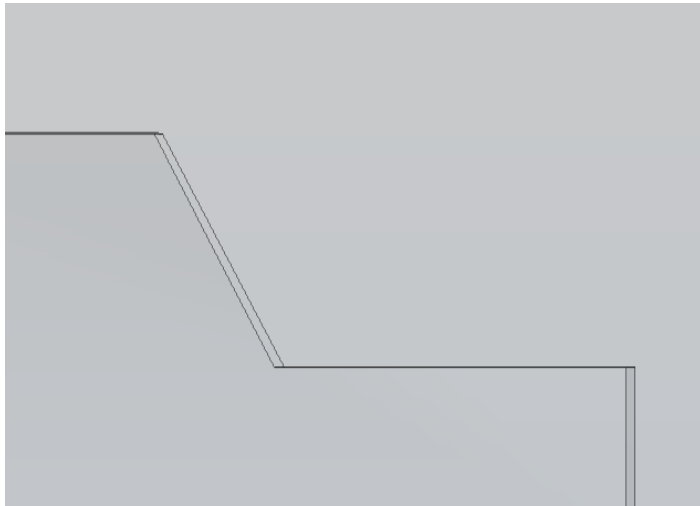


Comsol



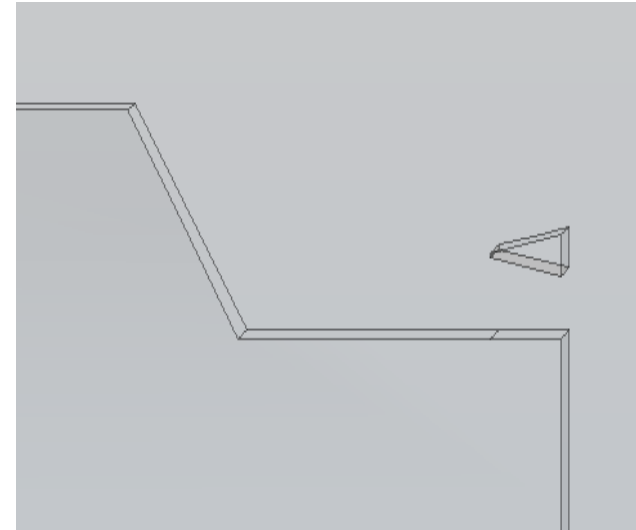
Spoiler Aerodynamic Properties – 2

No Spoiler



$C_d : 0.48$

Spoiler

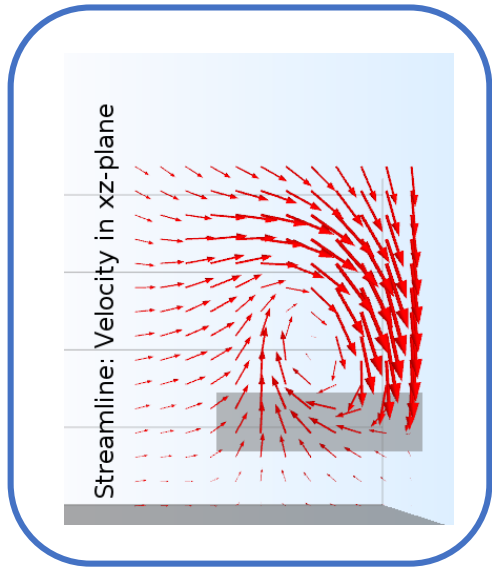


$C_d : 0.46$

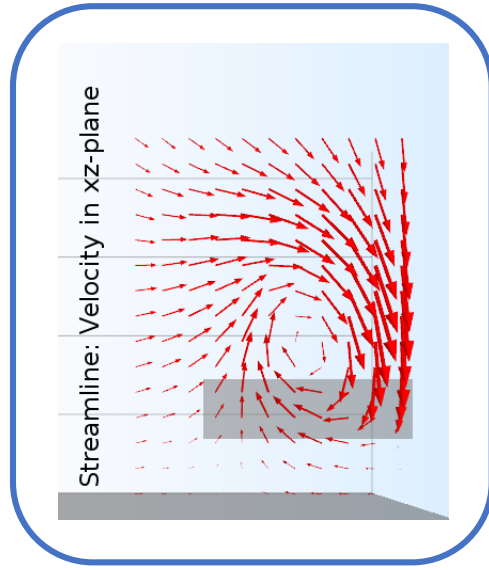


Cd 분석-no Spoiler(Blue), Spoiler(0도)(Red)

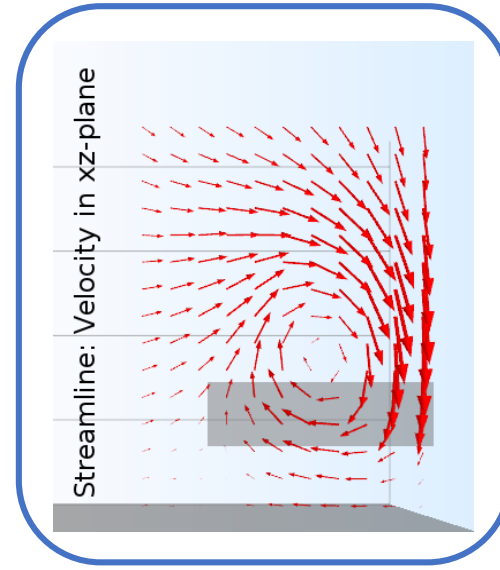
D: 자동차 뒷면으로 부터 떨어진 거리



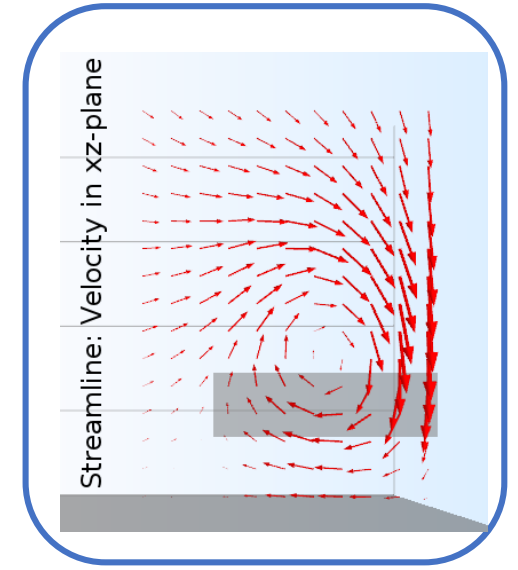
D=0.2



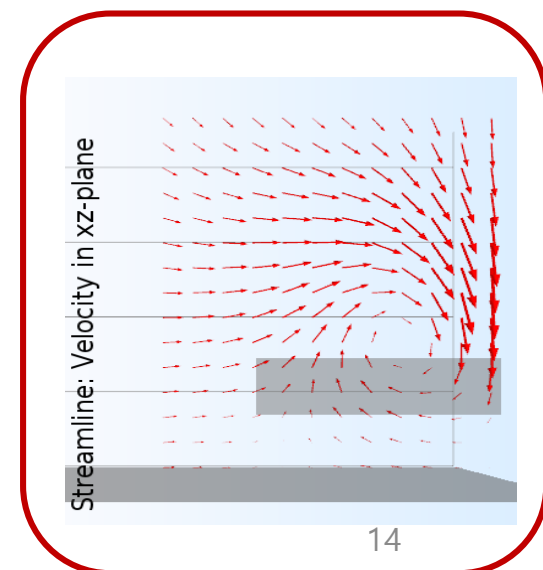
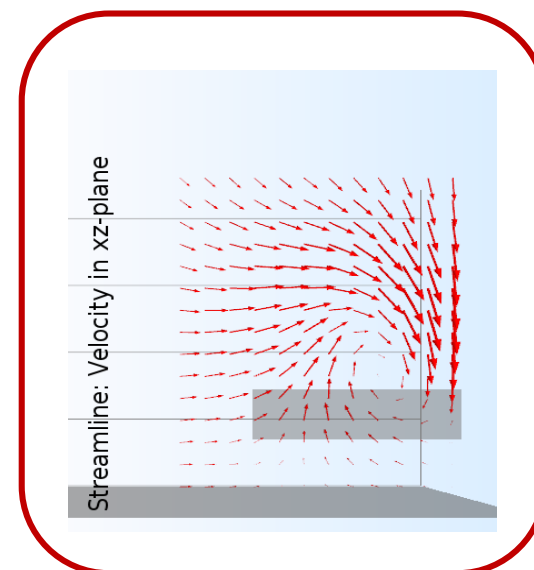
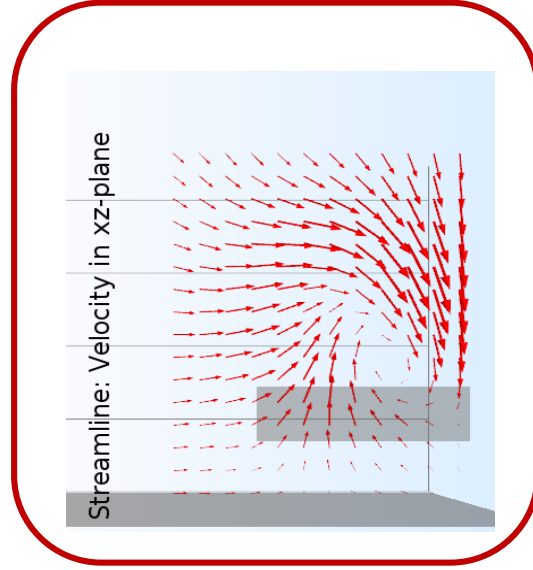
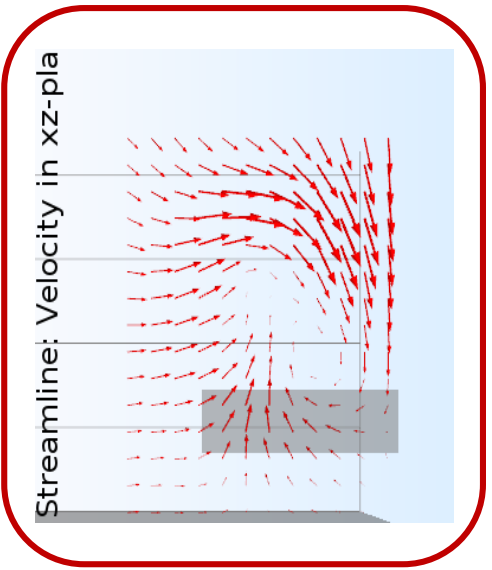
D=0.3



D=0.4

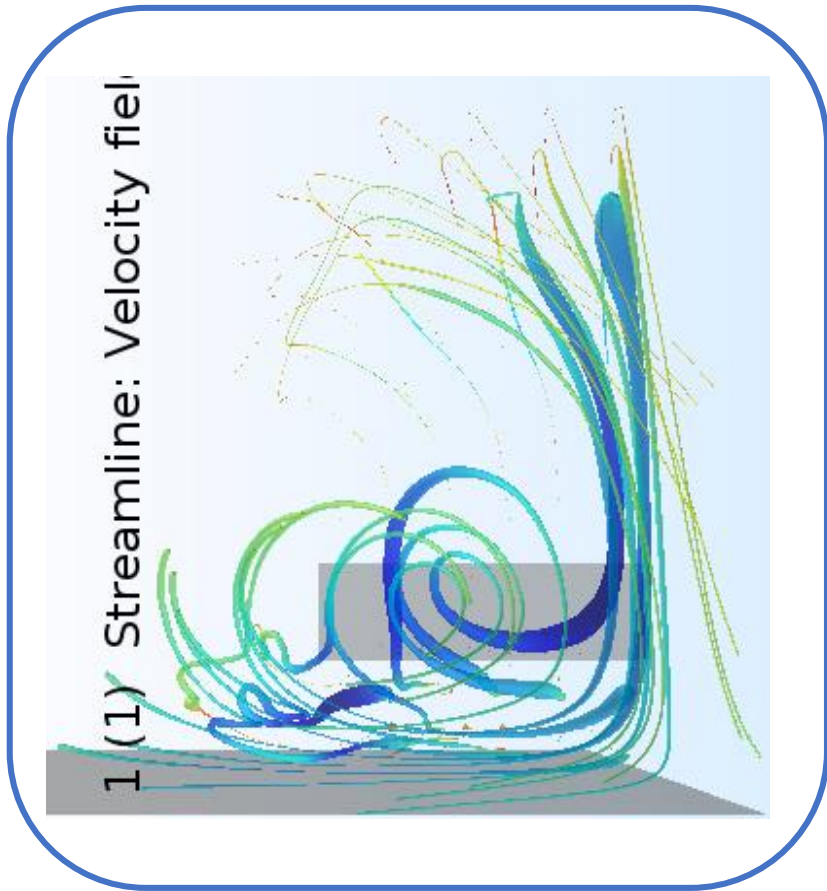


D=0.5

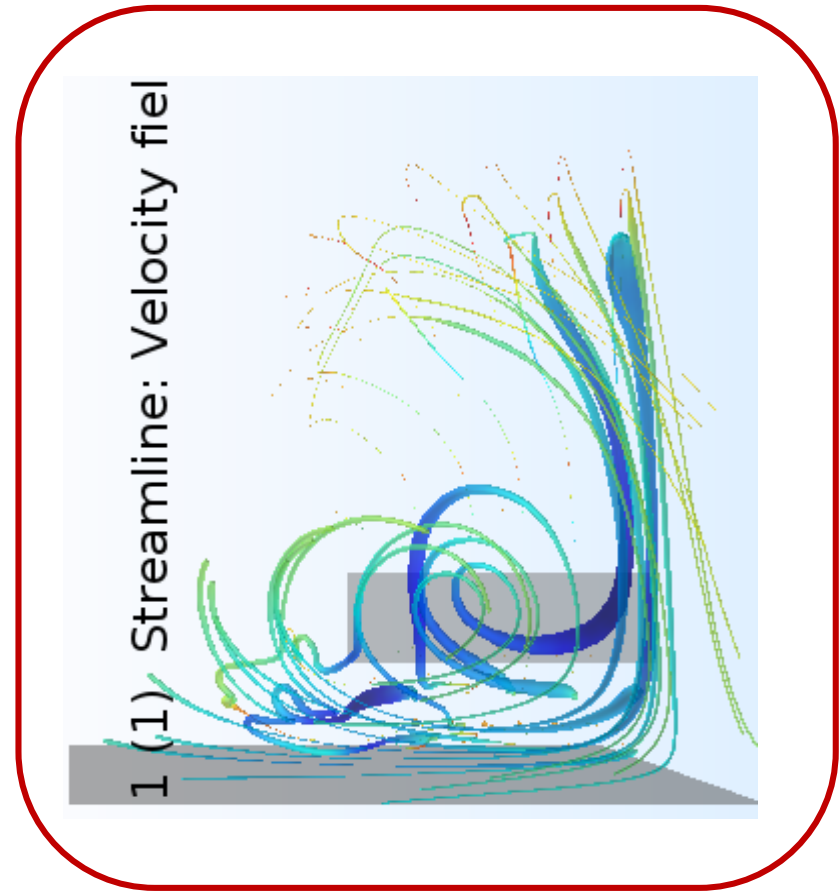


Cd 분석-no Spoiler, Spoiler(0도)

NO Spoiler

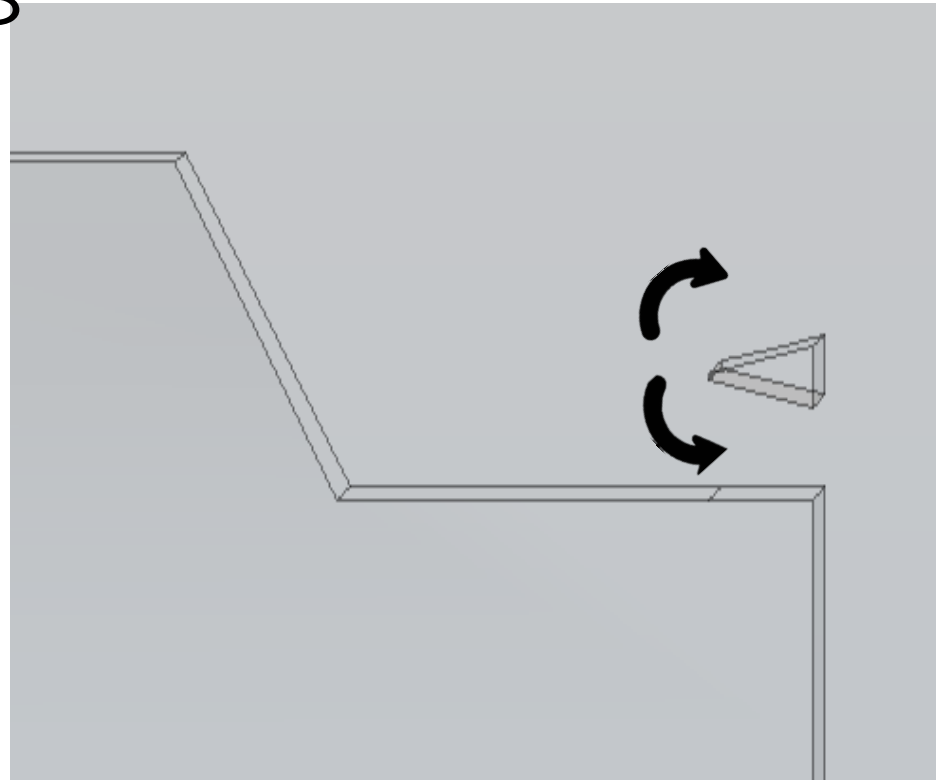


Spoiler



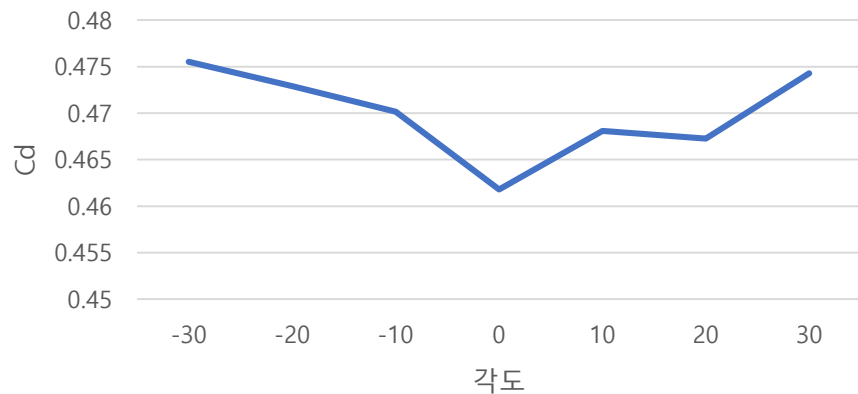
Spoiler Aerodynamic Properties – 3

Spoiler 각도에 따른 Lift와 Drag 측정

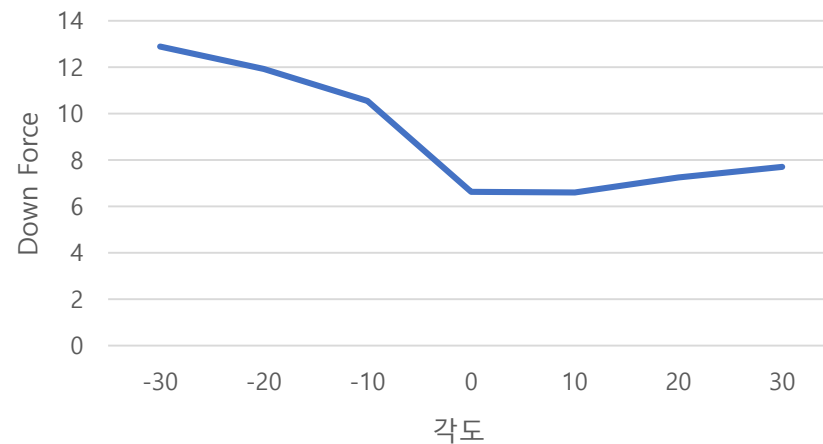


Spoiler Aerodynamic Properties – 3

각도 vs Cd



각도 vs Down Force



결과

Downforce 최대 각도 : -30도

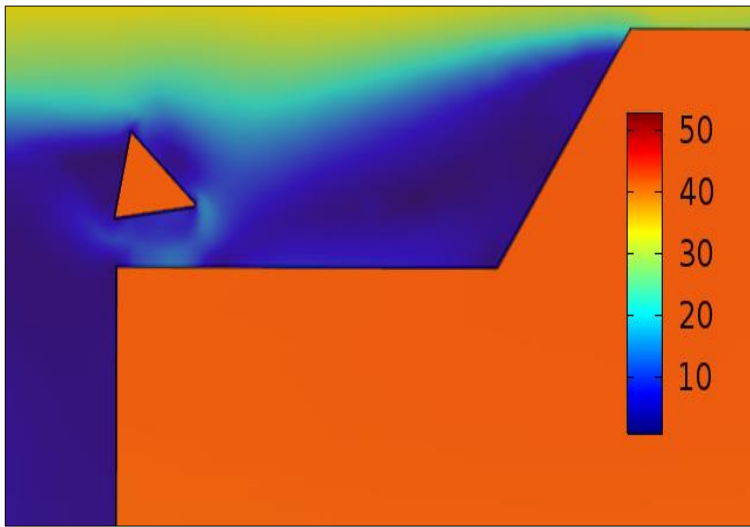
Downforce 최소 각도 : 0도

Cd 최대 각도 : -30도

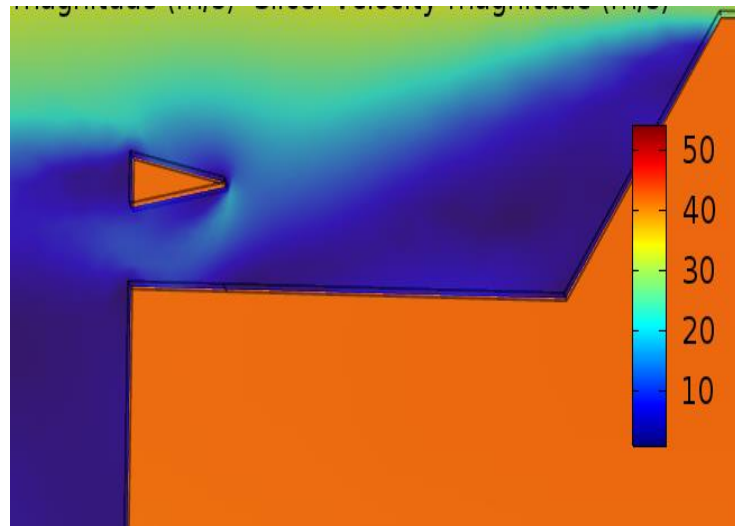
Cd 최소 각도 : 0도

	0도	-30도
연비	↑	↓
안정성	↓	↑

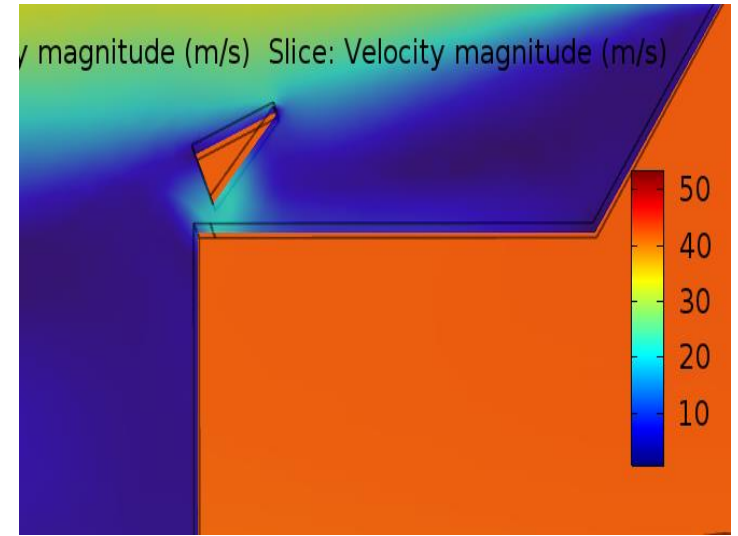
Down force 분석



-30도



0도

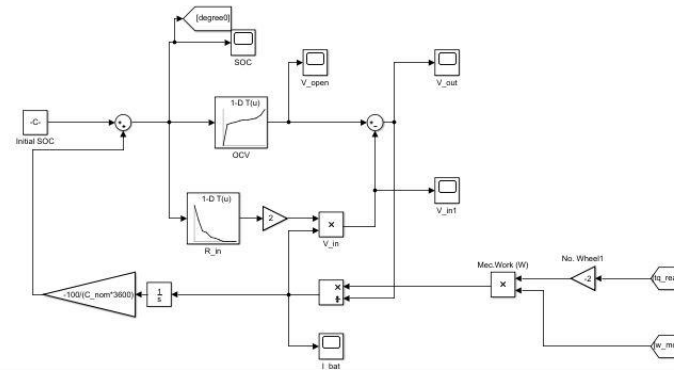
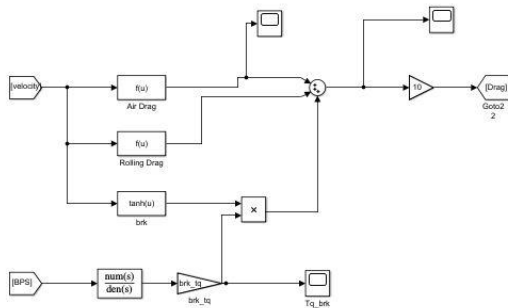
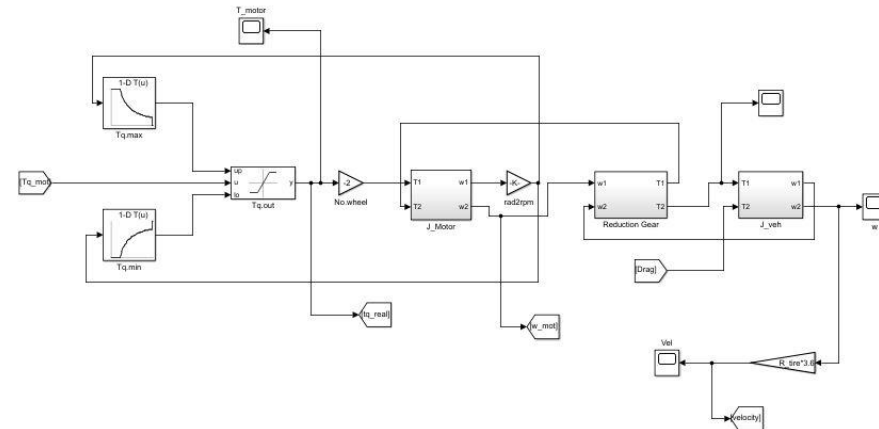
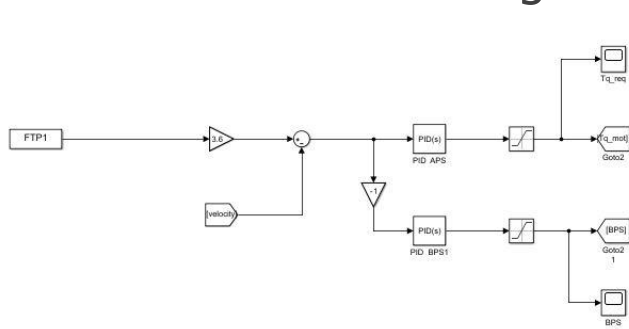


30도

SOC

Soc를 이용한 효율 계산

Simulink Modeling for SOC

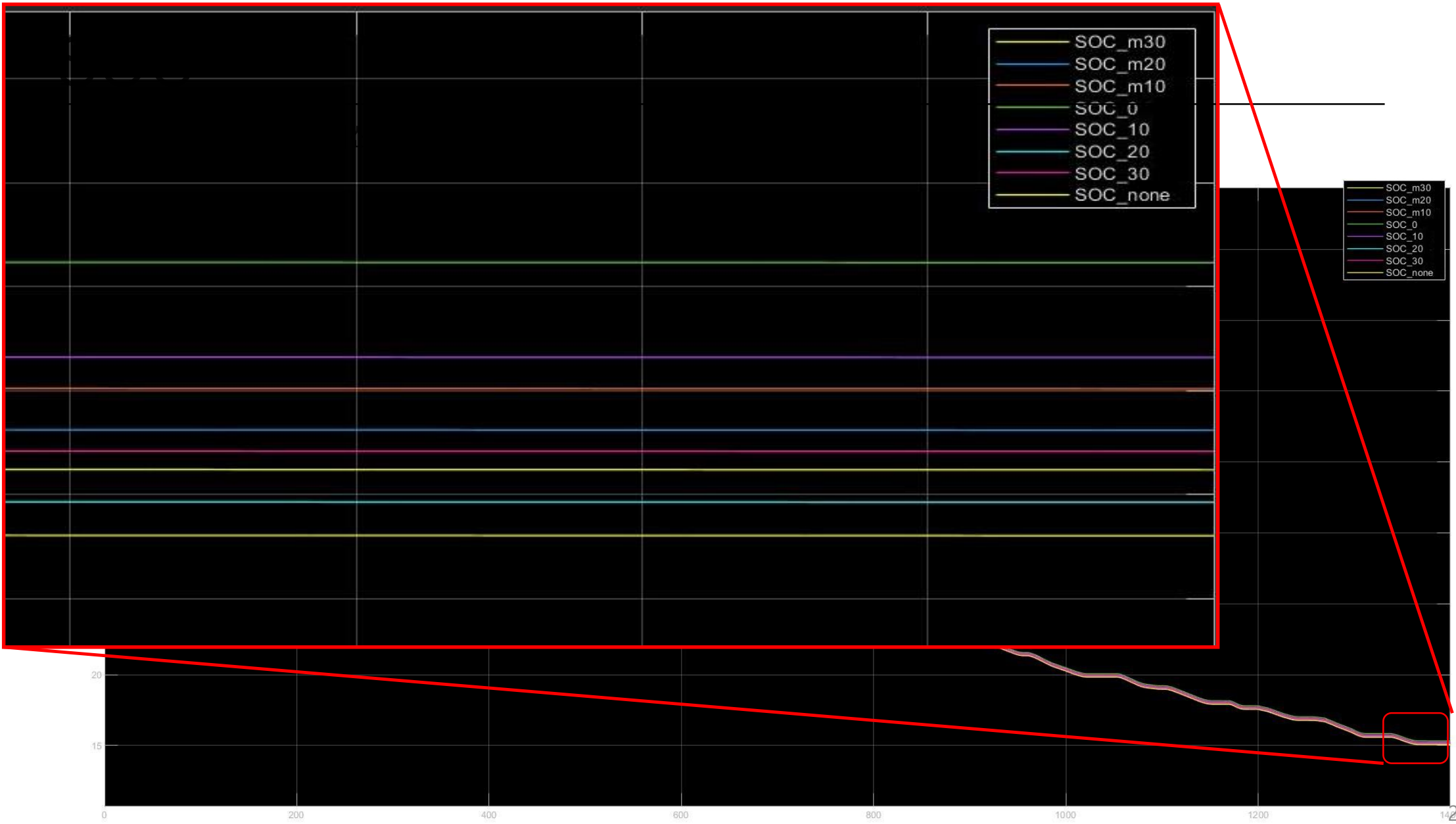


SOC

Soc를 이용한 효율 계산

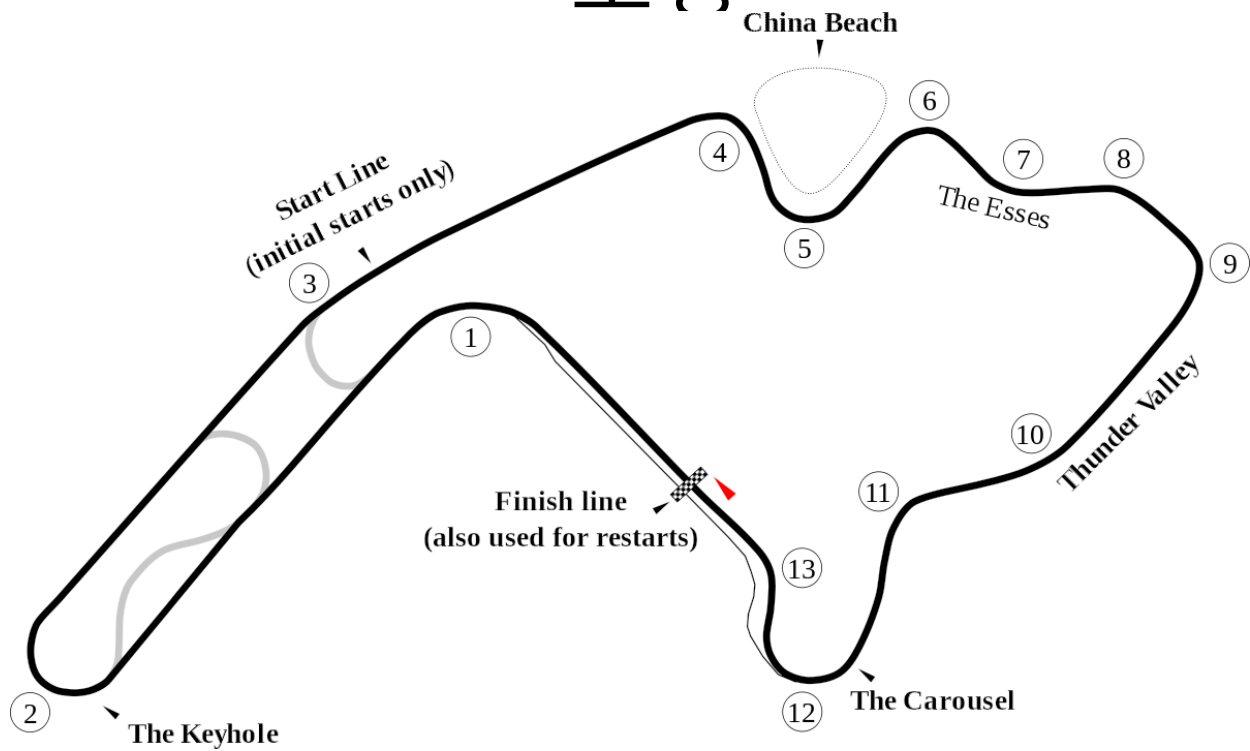
- ◎ Volvo 740 을 전기차로 가정.
- ◎ 모델의 값을 Volvo 740에 맞도록 변경.
- ◎ 모델의 상황을 연구하고자 하는 상황의 조건으로 변경.





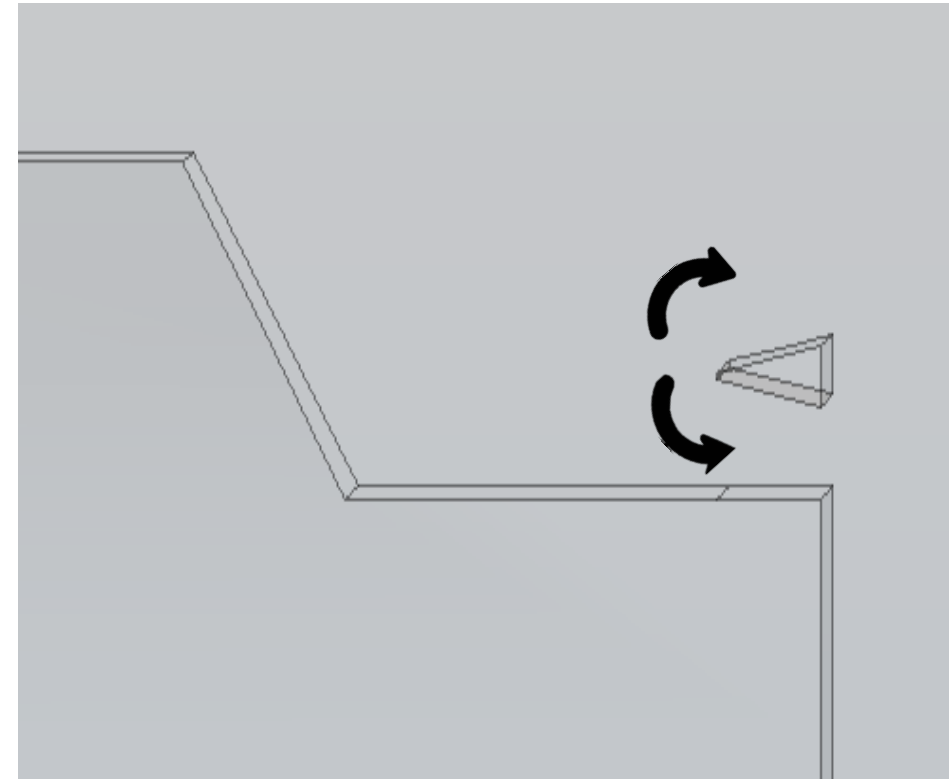
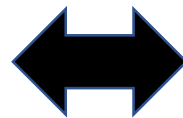
PID 제어

실제 도로에 따른 Active Spoiler 조정



Mid-Ohio Sports Car Course

제어



PID 제어

Conditions

조건

- ⊙ 직선 구간은 연비 효율을 고려한 최소한의 drag force를 받는 0도
- ⊙ 코너링 구간은 안정성을 고려하여 속도와 회전 반경에 따라 5단계로 나누어 각도 제어

15m/s 결과표

	cd	cl
-30	5.371	0.004434
-20	5.2918	0.27903
-10	5.2833	0.28849
0	5.2196	0.81336
10	5.2575	0.66135
20	5.269	0.69892
30	5.3526	0.50476



회전 속도	High	Medium	Low
High	(1)	(2)	(3)
Medium	(2)	(3)	(4)
low	(3)	(4)	(5)

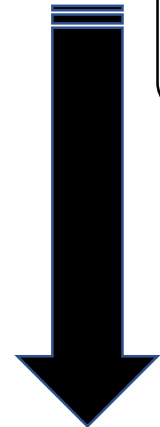
(1) : -20도

(2) : -10도

(3) : 30도

(4) : 10도

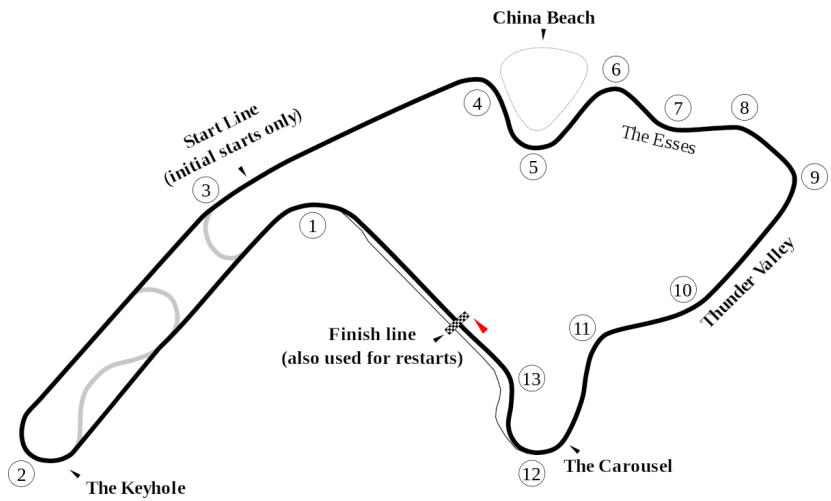
(5) : 20도



Small Lift & Stable

PID 제어

Catia, Simulink를 이용한 Modeling

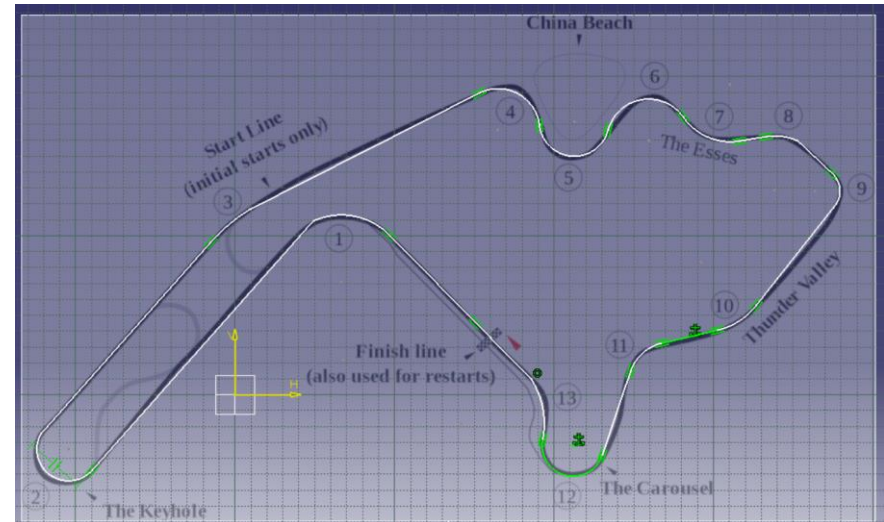


trace



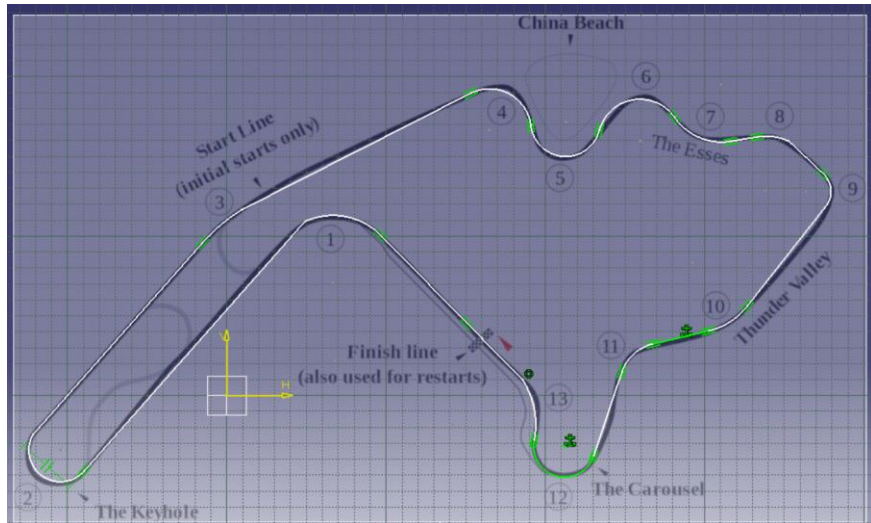
좌표화

Catia

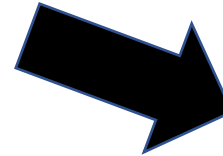
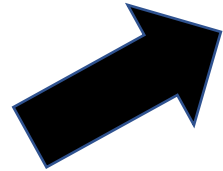


PID 제어

Catia, Simulink를 이용한 Modeling



Angular Velocity



Tangential Velocity

Block Parameters: 1-D Lookup Table1

Lookup Table (n-D)
Perform n-dimensional interpolated table lookup including index searches. The table is a sampled representation of a function in N variables. Breakpoint sets relate the input values to positions in the table. The first dimension corresponds to the top (or left) input port.

Table and Breakpoints Algorithm Data Types

Number of table dimensions: 1

Data specification: Table and breakpoints

Table data: [30 30 30 10 10 0 0 20 20 0 0 20 20 0 0 10 10 30 30 10 10 0 0 30 30 10 10 0]

Breakpoints specification: Explicit values

Breakpoints 1: [5.01 109 109.01 114 114.01 120 120.01 122 122.01 126 126.01 131 131.01 137]

Edit table and breakpoints...

OK Cancel Help Apply

Block Parameters: 1-D Lookup Table2

Lookup Table (n-D)
Perform n-dimensional interpolated table lookup including index searches. The table is a sampled representation of a function in N variables. Breakpoint sets relate the input values to positions in the table. The first dimension corresponds to the top (or left) input port.

Table and Breakpoints Algorithm Data Types

Number of table dimensions: 1

Data specification: Table and breakpoints

Table data: [50 50 144 144 60 60 144 144 40 40 60 60 50 50 144 144 60 60 40 40 144 144]

Breakpoints specification: Explicit values

Breakpoints 1: [5.01 109 109.01 114 114.01 120 120.01 122 122.01 126 126.01 131 131.01 137]

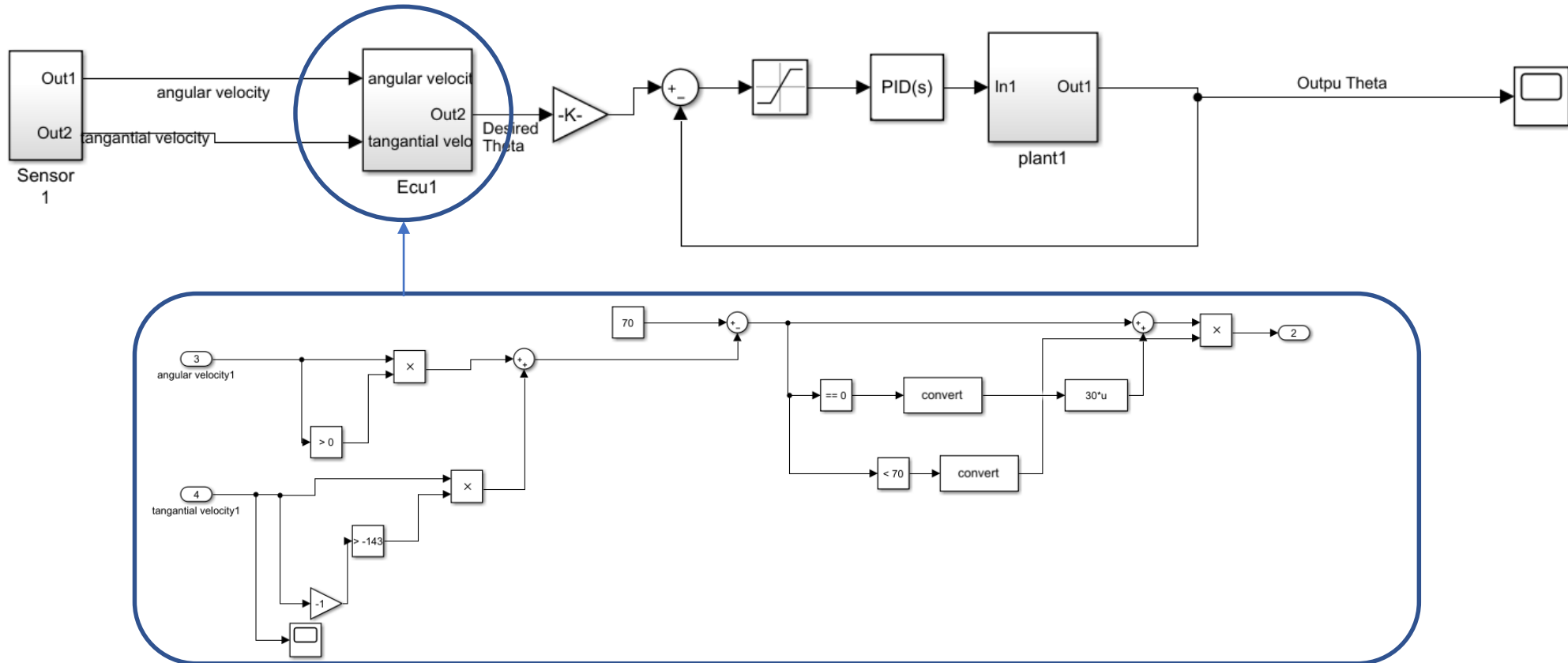
Edit table and breakpoints...

OK Cancel Help Apply

PID 제어

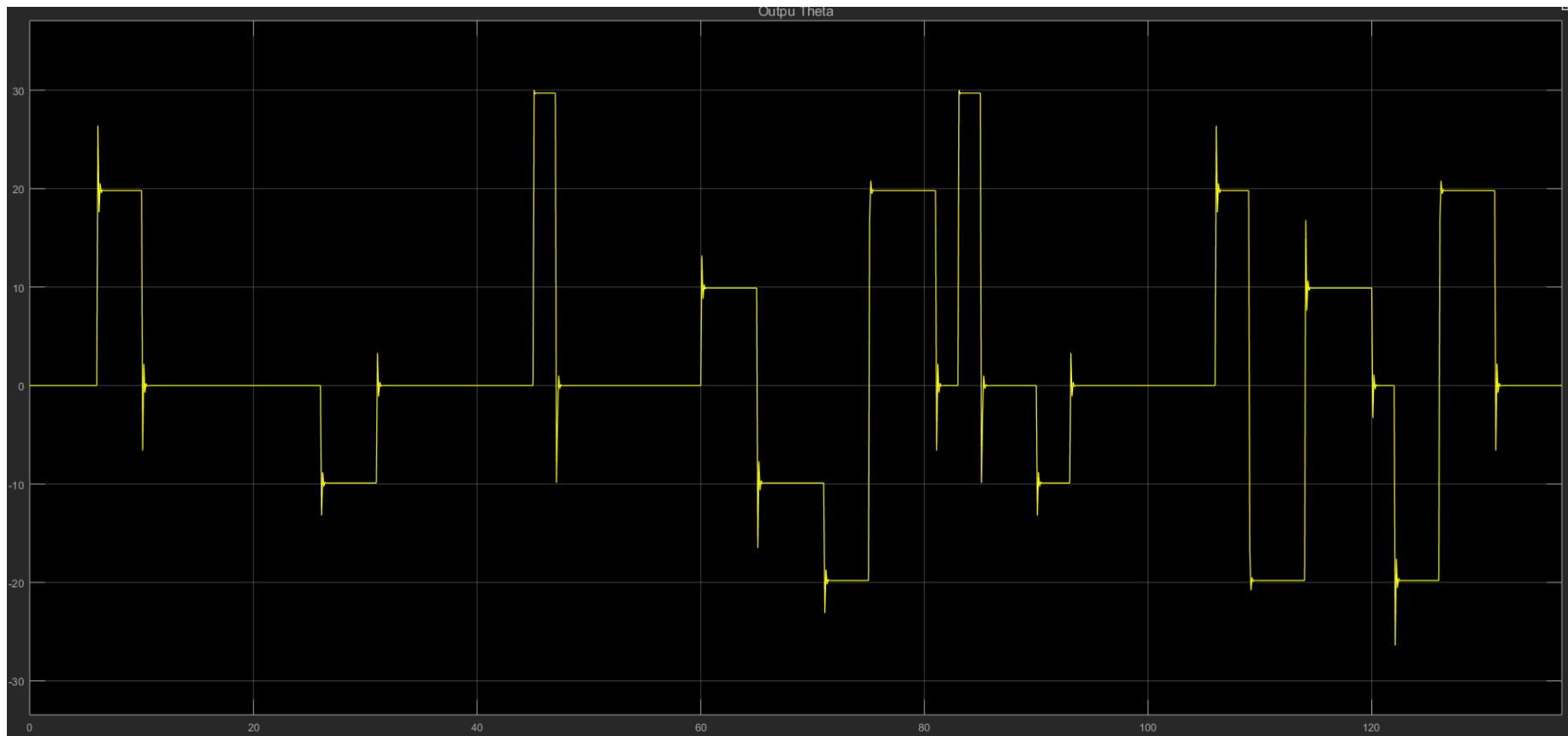
Catia, Simulink를 이용한 Modeling

Simulink



PID 제어

Comsol 결과 분석



Reference

- ◎ 유체역학 전공책 : "Introduction to Fluid Mechanics"
- Fox and McDonalds
- ◎ "Airflow Over an Ahmed Body"
- COMSOL Multiphysics 5.4
- ◎ "Effects of rear spoilers on ground vehicle aerodynamic drag"
- Halil Sadettin Hamut, Rami Salah El-Emam, Murat Aydin, Ibrahim Dincer
- ◎ "Evaluating the Importance of Rear Spoiler on Energy Efficiency of Electric Vehicles"
- S. M. R. Tousi¹, P. Bayat², P. Bayat³

