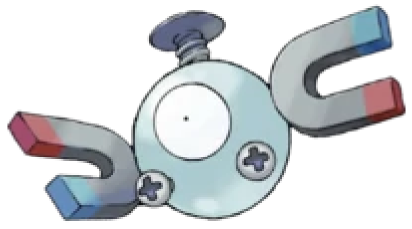
초전도 리니어 모터카의 작용력 분석

2014012524 변무경
2014012706 조준형
2014012715 조힘찬

팀명

코일
コイル 코이루
Magnemite

No.081



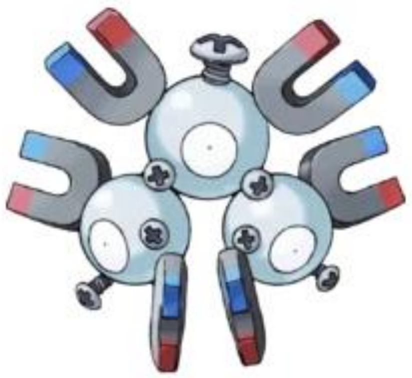
타입	분류
전기 강철 (2세대부터) 전기 (1세대)	자석포켓몬

×3

=

레어코일
レアコイル 레아코이루
Magneton

No.082



타입	분류
전기 강철 (2세대부터) 전기 (1세대)	자석포켓몬

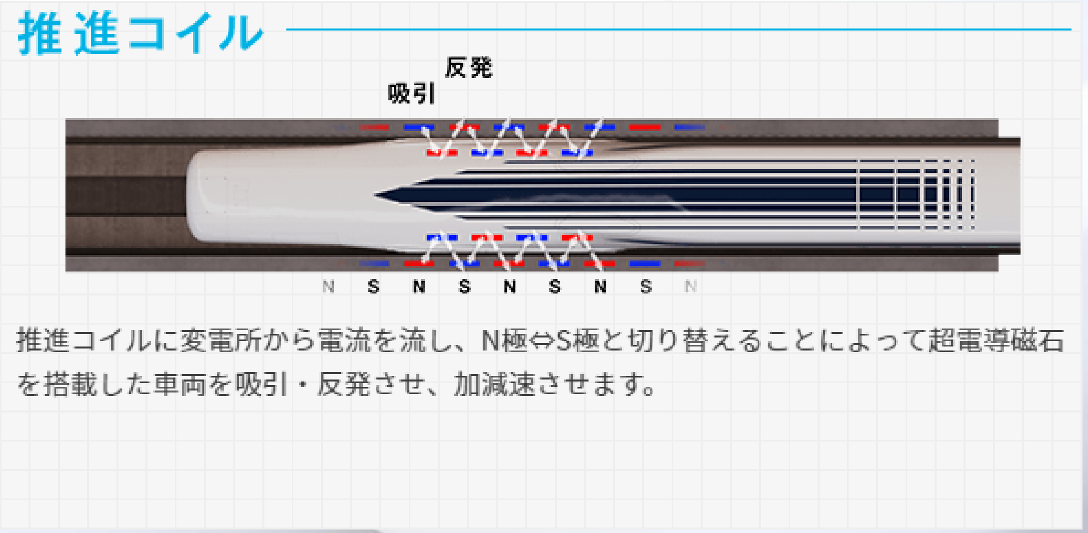
Magnetic Levitation

Electromagnetic levitation (EMS)

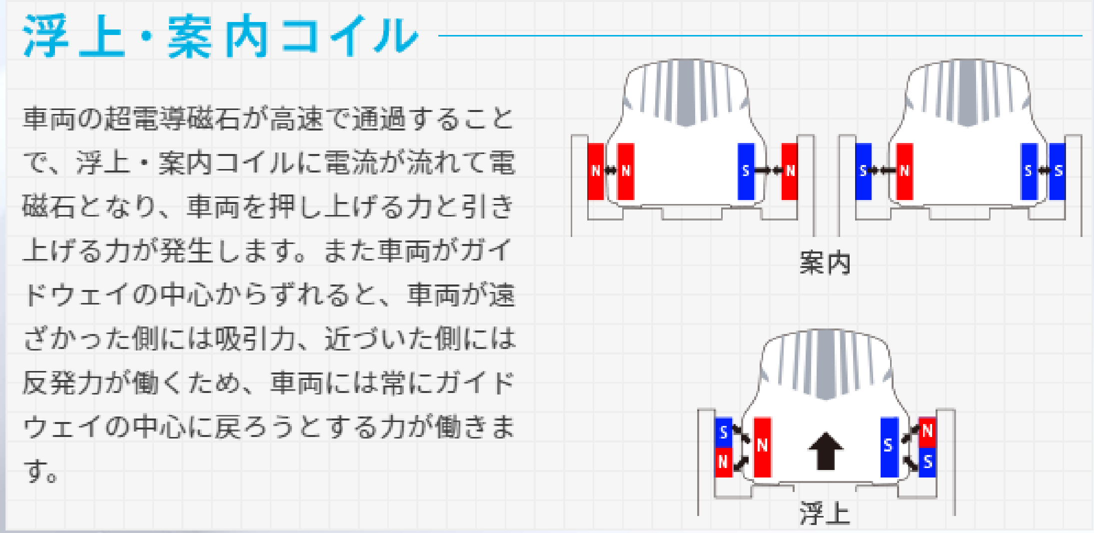
Electrodynamic levitation (EDS)

Electrodynamic suspension

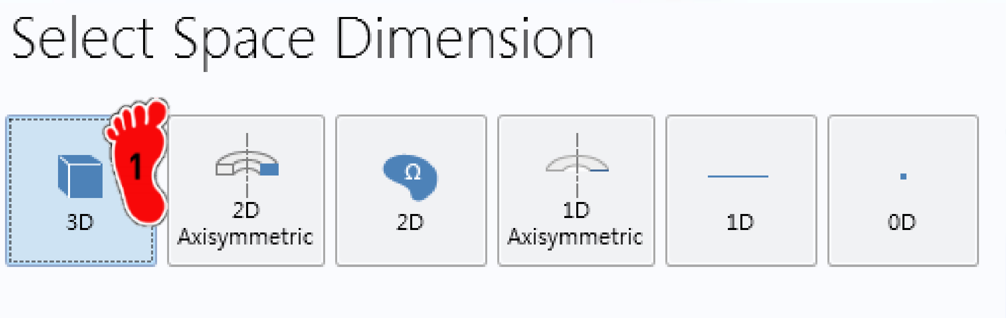
추진 코일

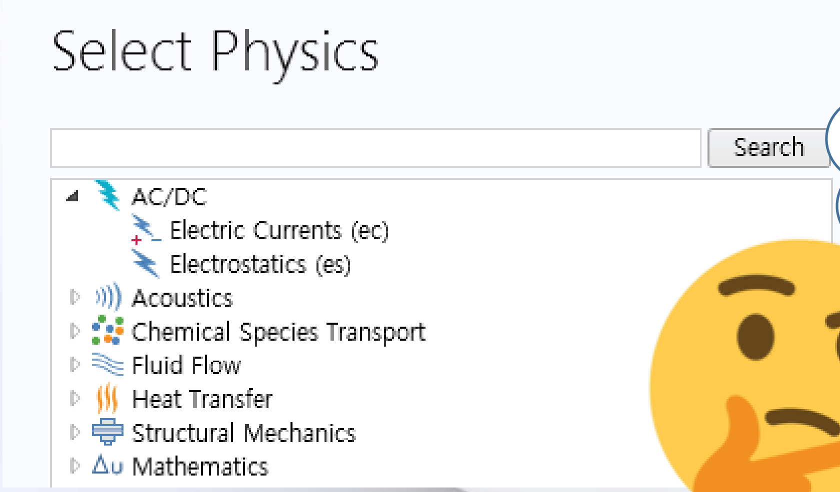


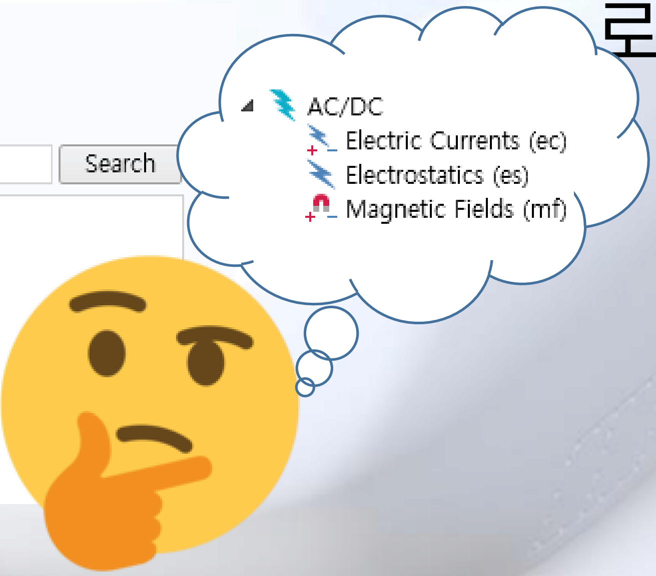
부상·안내 코일



모델링 – 부상력, 안내력, 저항력







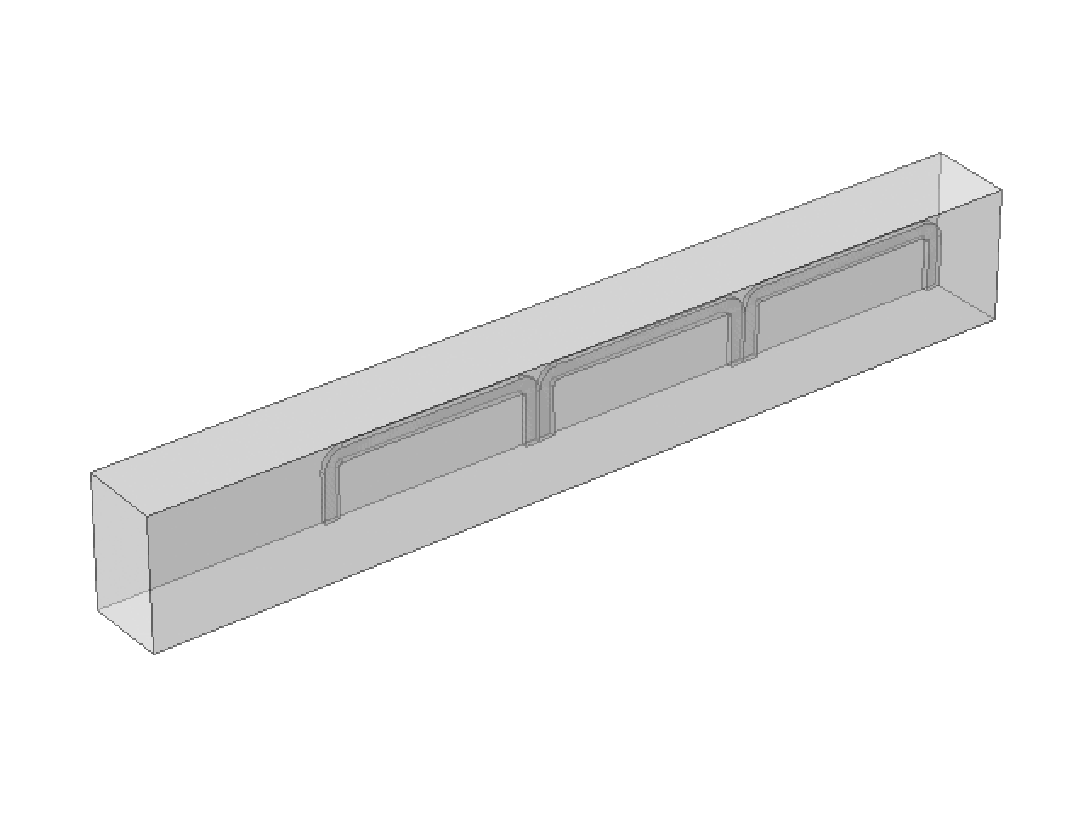
자기장 계산(COMSOL)

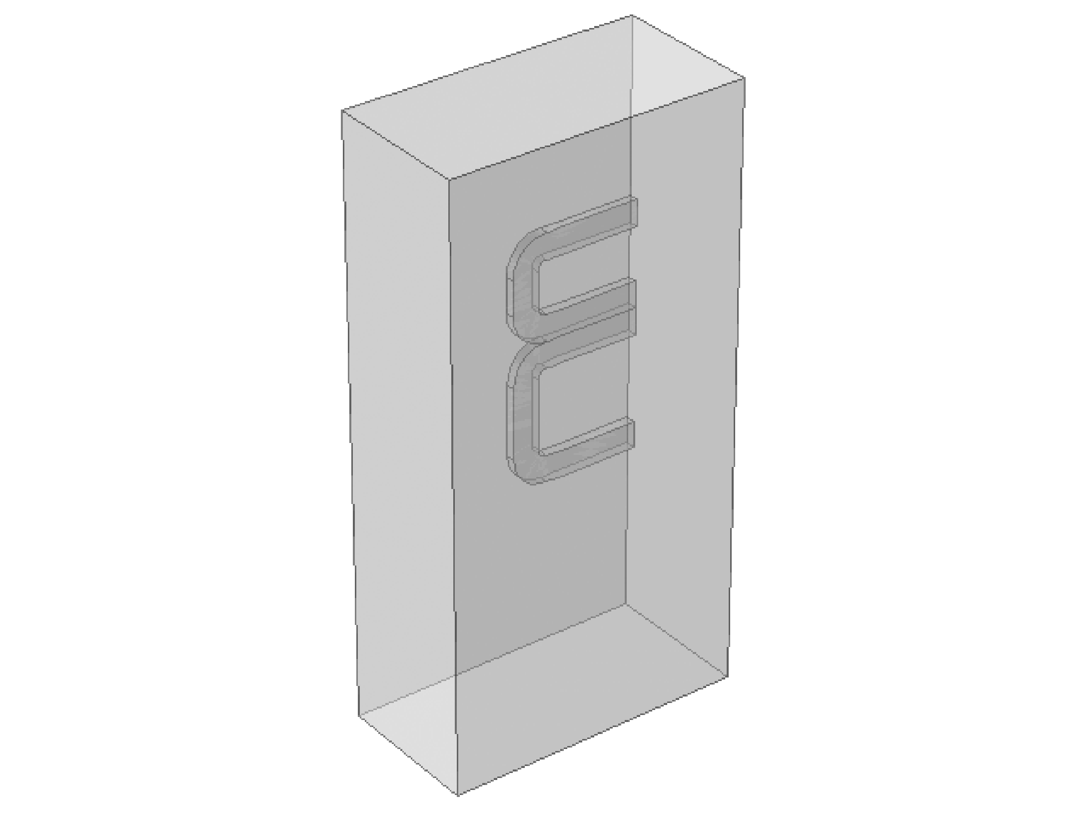
→ 유도기전력 계산(Excel+MATLAB)

→ 유도전류 계산(MATLAB)

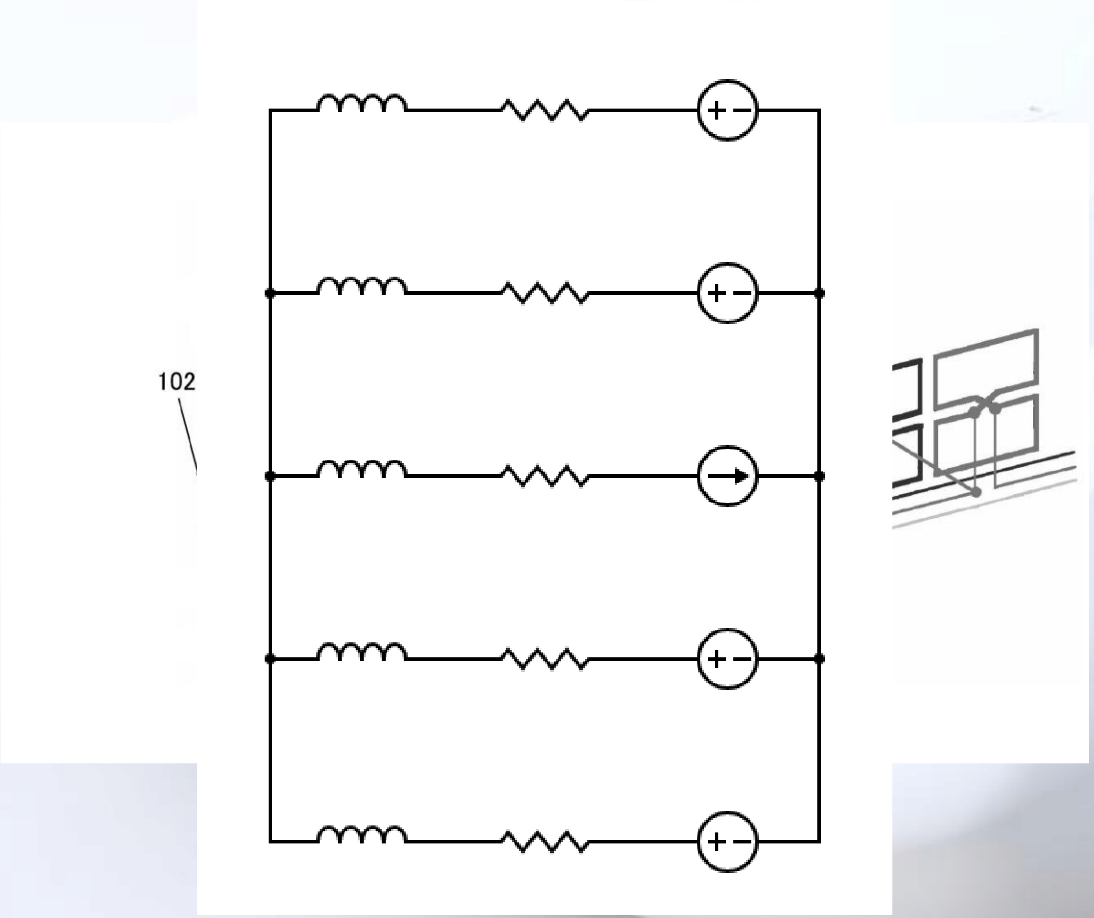
로렌츠 힘 계산(MATLAB)

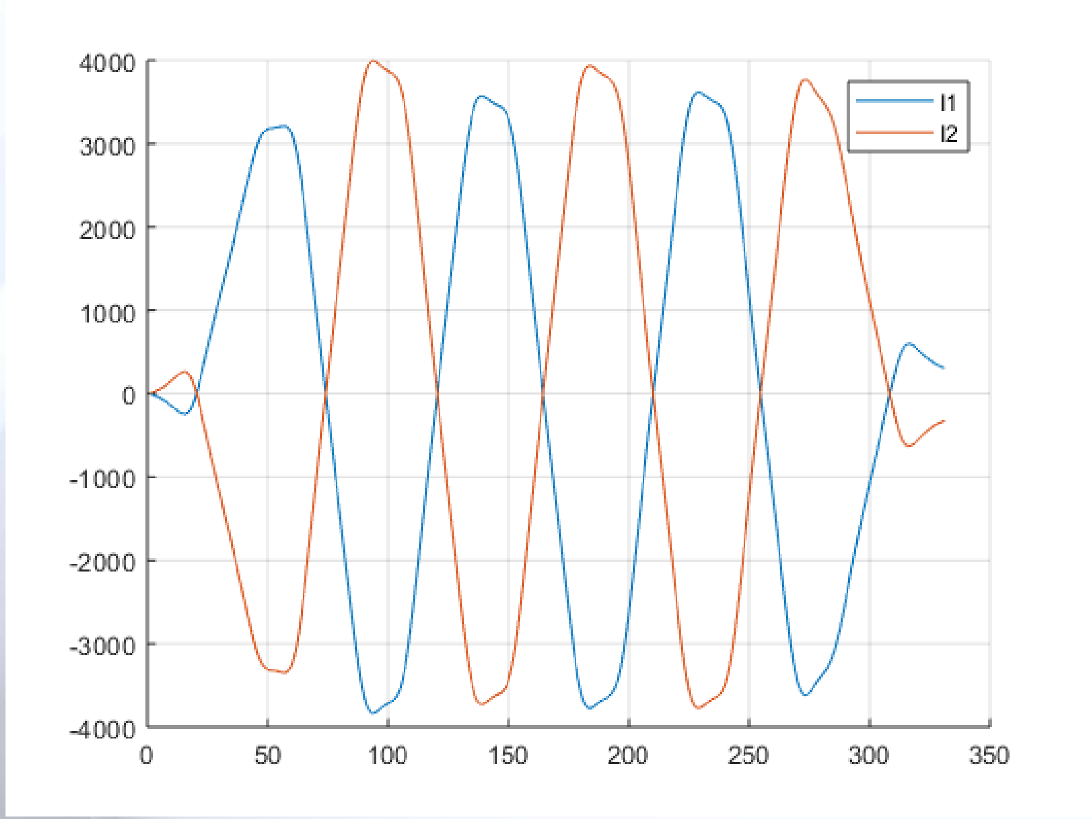
모델링 – 부상력, 안내력, 저항력





모델링 – 부상력, 안내력, 저항력





모델링 – 부상력, 안내력, 저항력

COMSOL

- Parametric sweep
- Force computation
- 한 조건 계산에 30분 소요
- 속도 조건 10개
- 변위 조건 25개
- 최소 소요시간 5일 이상

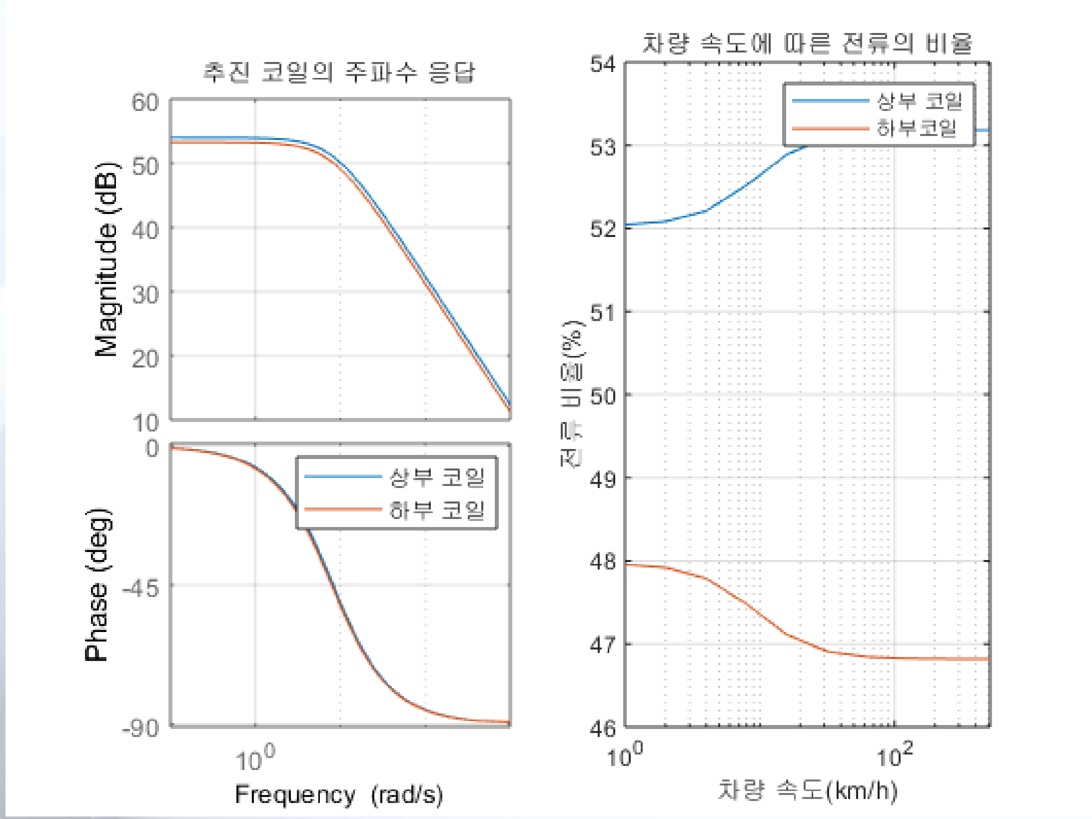
MATLAB

- $\vec{\mathrm{F}} = \int i(d\vec{L} \times \vec{B}) \approx \sum i\left(\Delta\vec{L} \times \vec{B}\right)$
- 소요시간 10분 내외

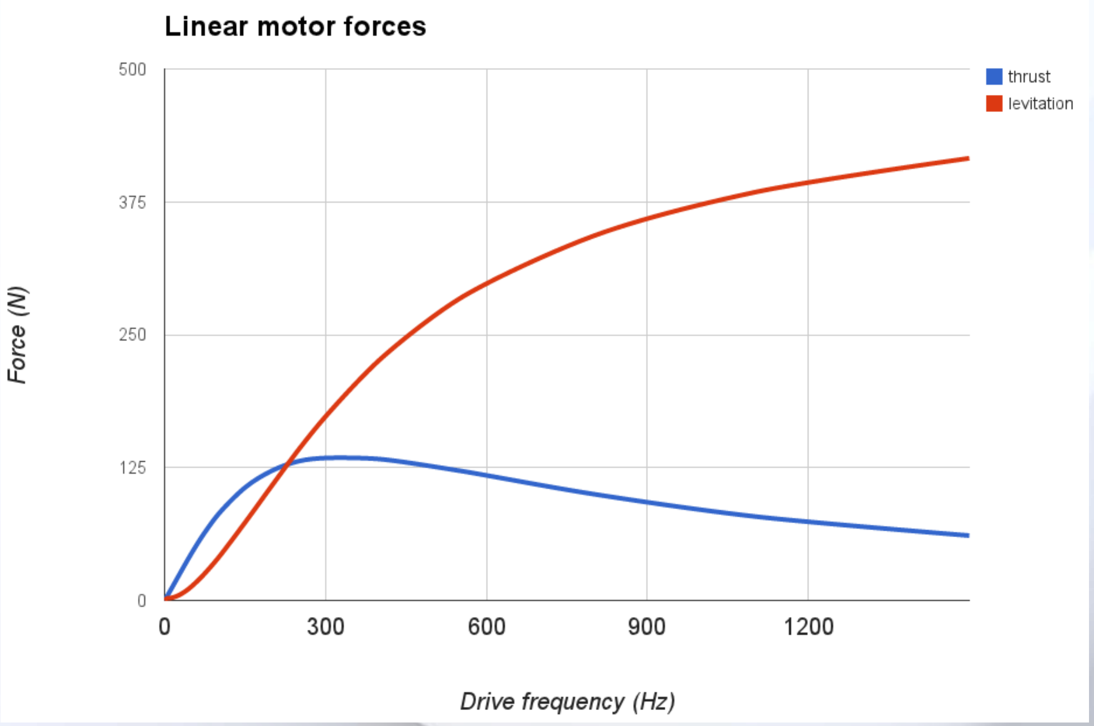
모델링 – 추진력

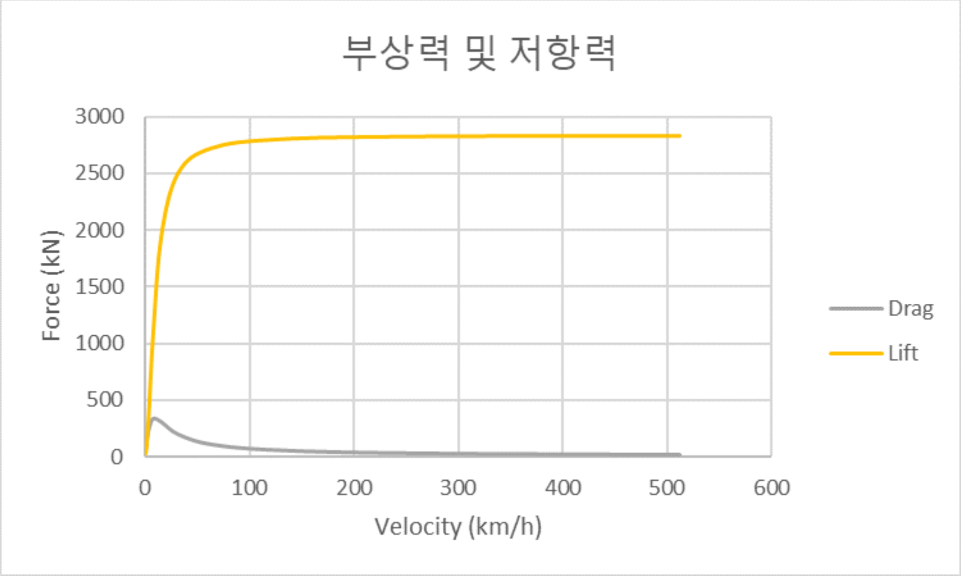
- 속도마다 다른 전류 응답

- $\vec{\mathrm{F}} = \int i(d\vec{L} \times \vec{B}) \approx \sum i\left(\Delta\vec{L} \times \vec{B}\right)$
- MATLAB으로 효율이 가장 좋은 3상 전류 위상 구함(1°단위)

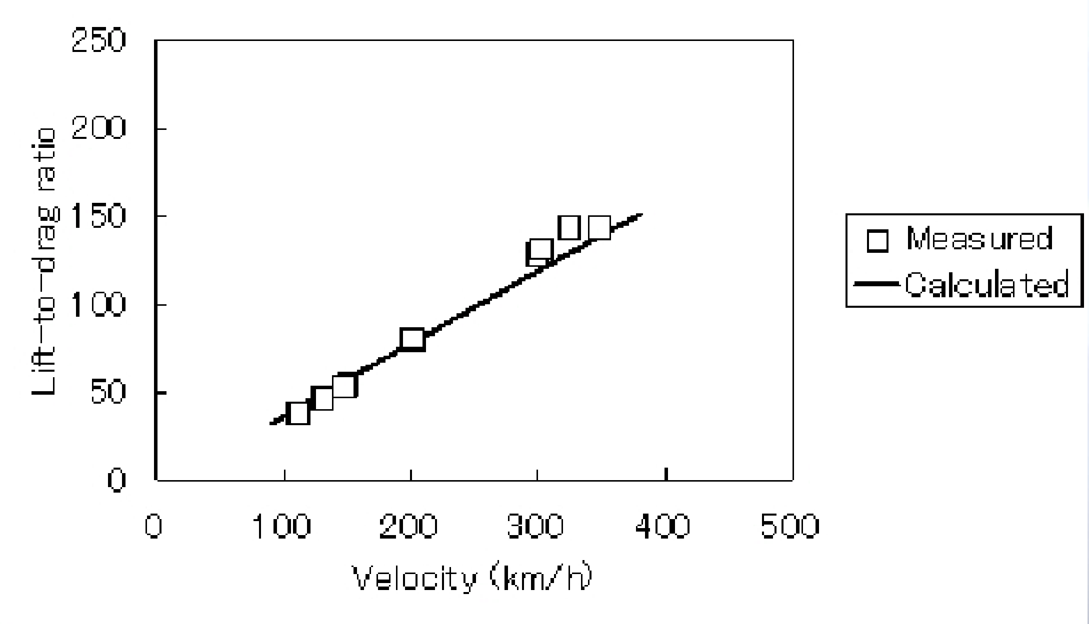


모델링 – 결과

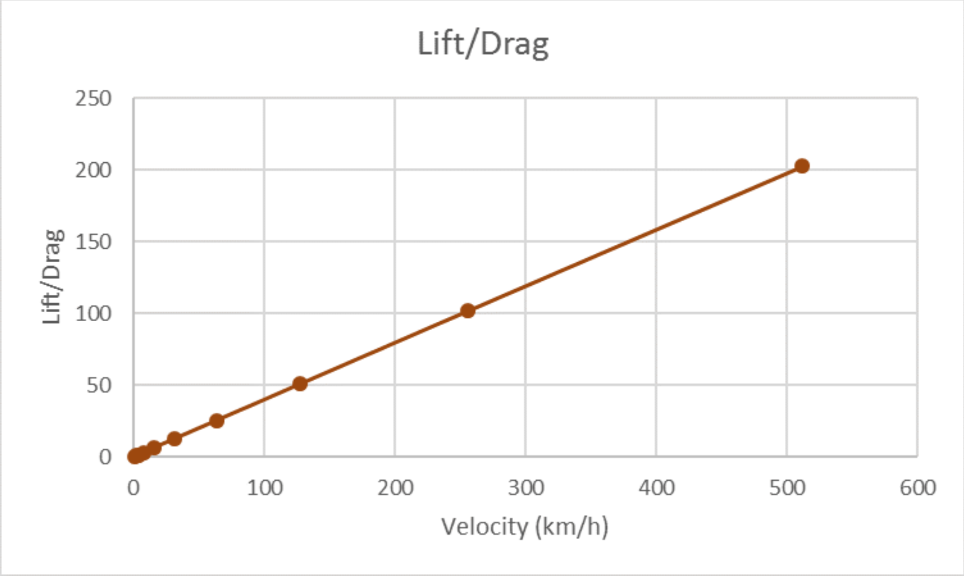

Linear motor forces
500
375
250
125
0
Force (N)
thrust
levitation
0
300
600
900
1200
Drive frequency (Hz)


부상력 및 저항력
3000
2500
2000
1500
1000
500
0
Force (kN)
0
100
200
300
400
500
600
Velocity (km/h)
Drag
Lift

모델링 – 결과

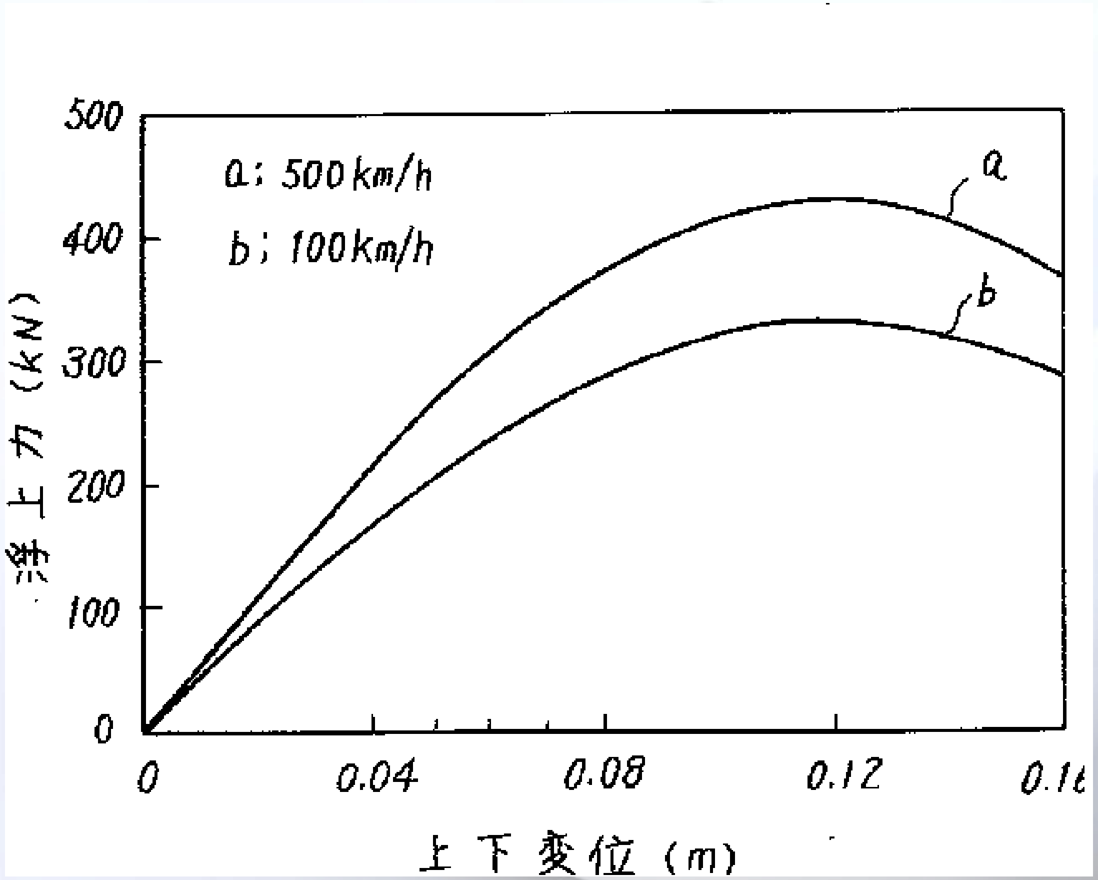


Lift-to-drag ratio
250
200
150
100
50
0
0
100
200
300
400
500
Velocity (km/h)
Measured
Calculated

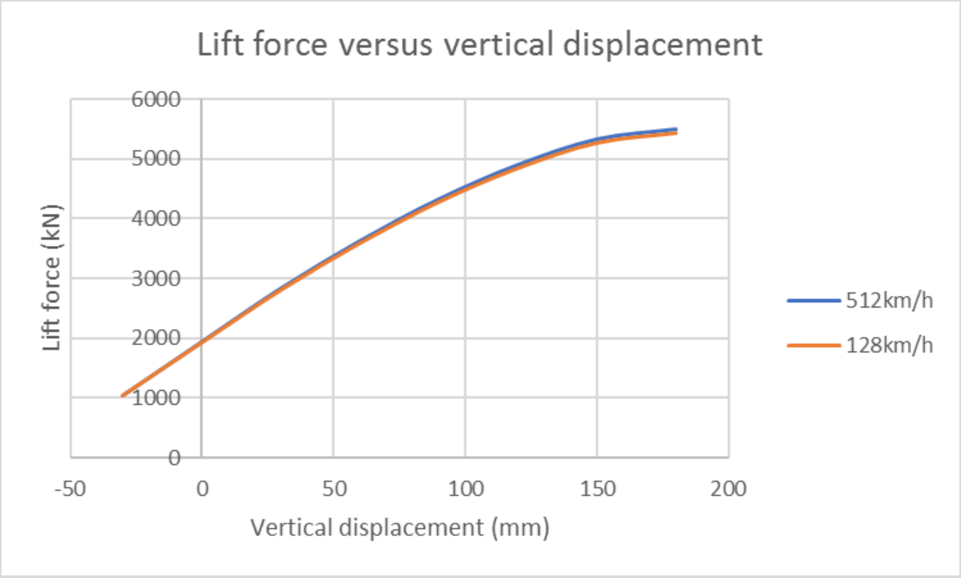


Lift/Drag
Lift/Drag
250
200
150
100
50
0
0
100
200
300
400
500
600
Velocity (km/h)

모델링 – 결과

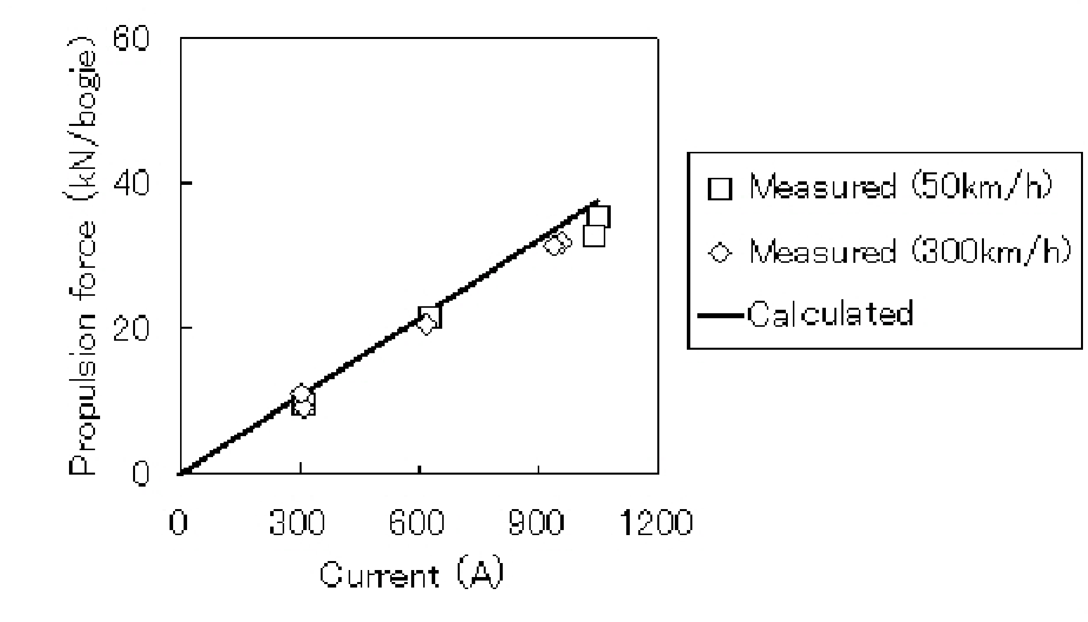


a: 500km/h
b: 100km/h
a
b
500
400
300
200
100
0
0
0.04
0.08
0.12
浮上力 (kN)
上下変位 (m)

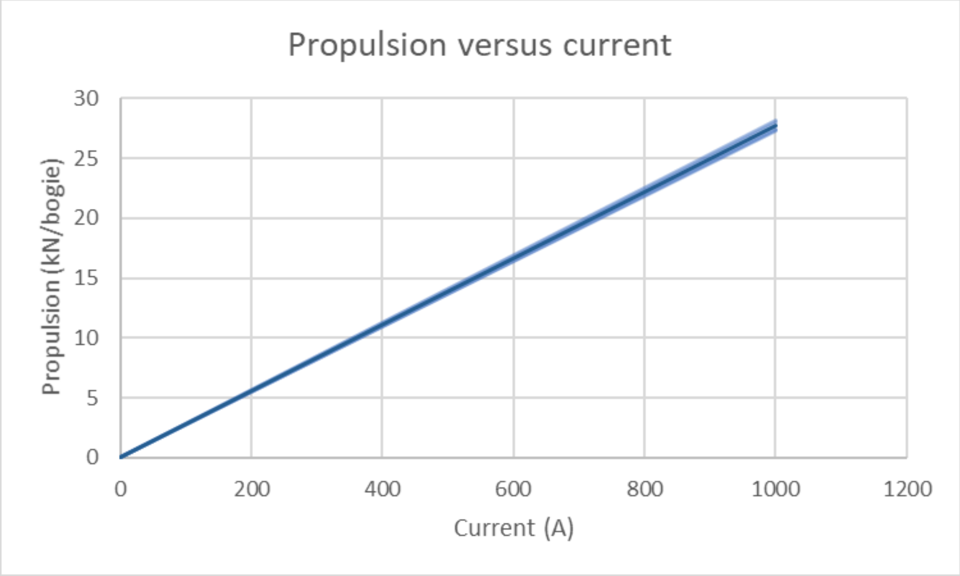


Lift force versus vertical displacement
6000
5000
4000
3000
2000
1000
0
-50
0
50
100
150
200
Lift force (kN)
Vertical displacement (mm)
512km/h
128km/h

모델링 – 결과



Propulsion force (kN/bogie)
60
40
20
0
0
300
600
900
1200
Current (A)
Measured (50km/h)
Measured (300km/h)
Calculated



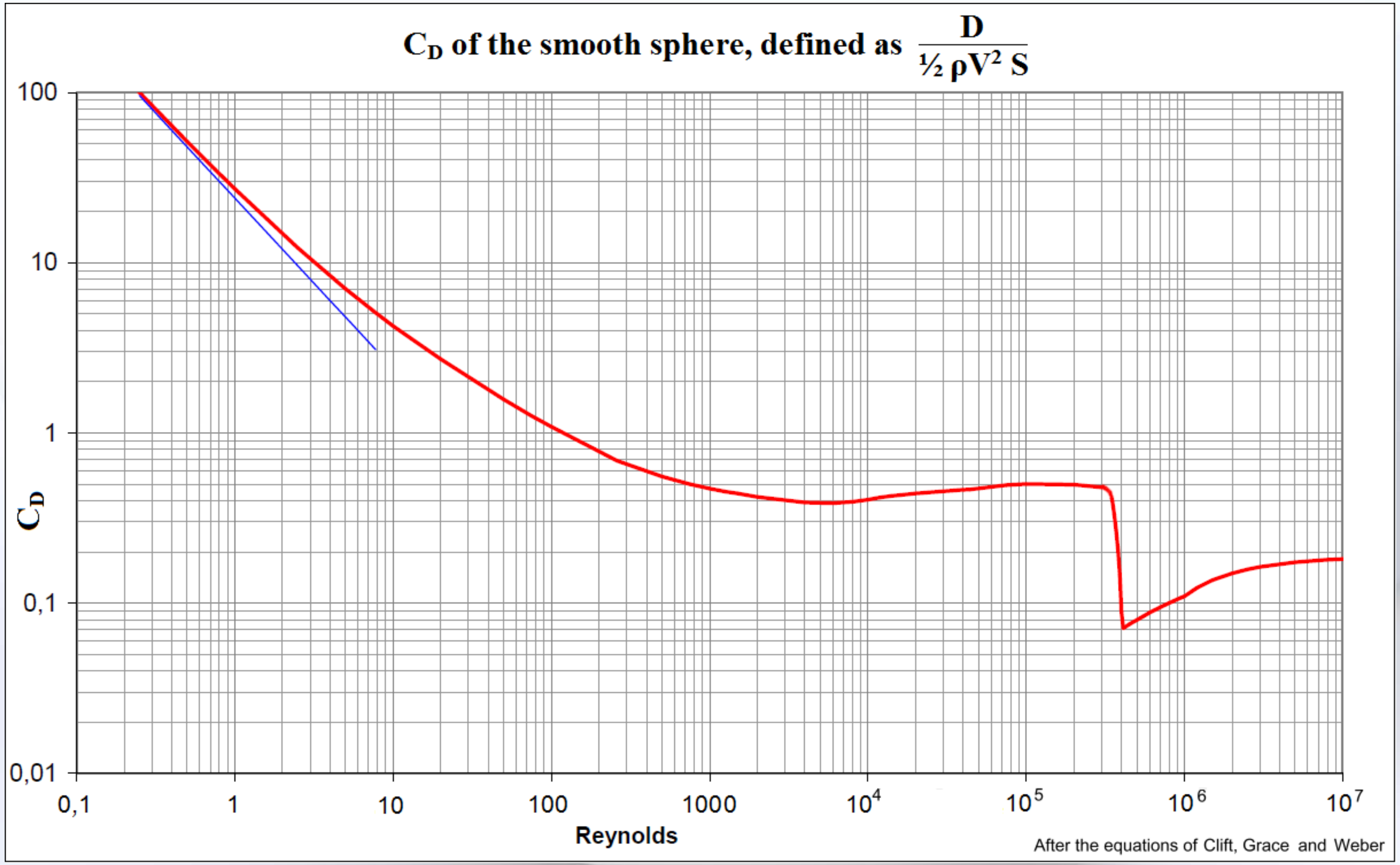
Propulsion versus current
Propulsion (kN/bogie)
30
25
20
15
10
5
0
0
200
400
600
800
1000
1200
Current (A)

모델링 – 결과

SC current: 500kA	128 km/h	256 km/h	512 km/h
저항력 (kN)	55	28	14
부상력 (kN)	2805	2829	2836
부상력 리플	8.4%	8.3%	8.3%
추진력 (kN/kA)	366	355	366
수직 유효 스프링 상수 (MN/m)	27.1	27.4	27.5
수직 유효 감쇠비	25	25	25
수평 유효 스프링 상수 (MN/m)	143	144	144
수평 유효 감쇠비	84	84	84

※조건: 선로 중앙, 수직변위 3cm, 12량 편성

모델링 – 공기저항

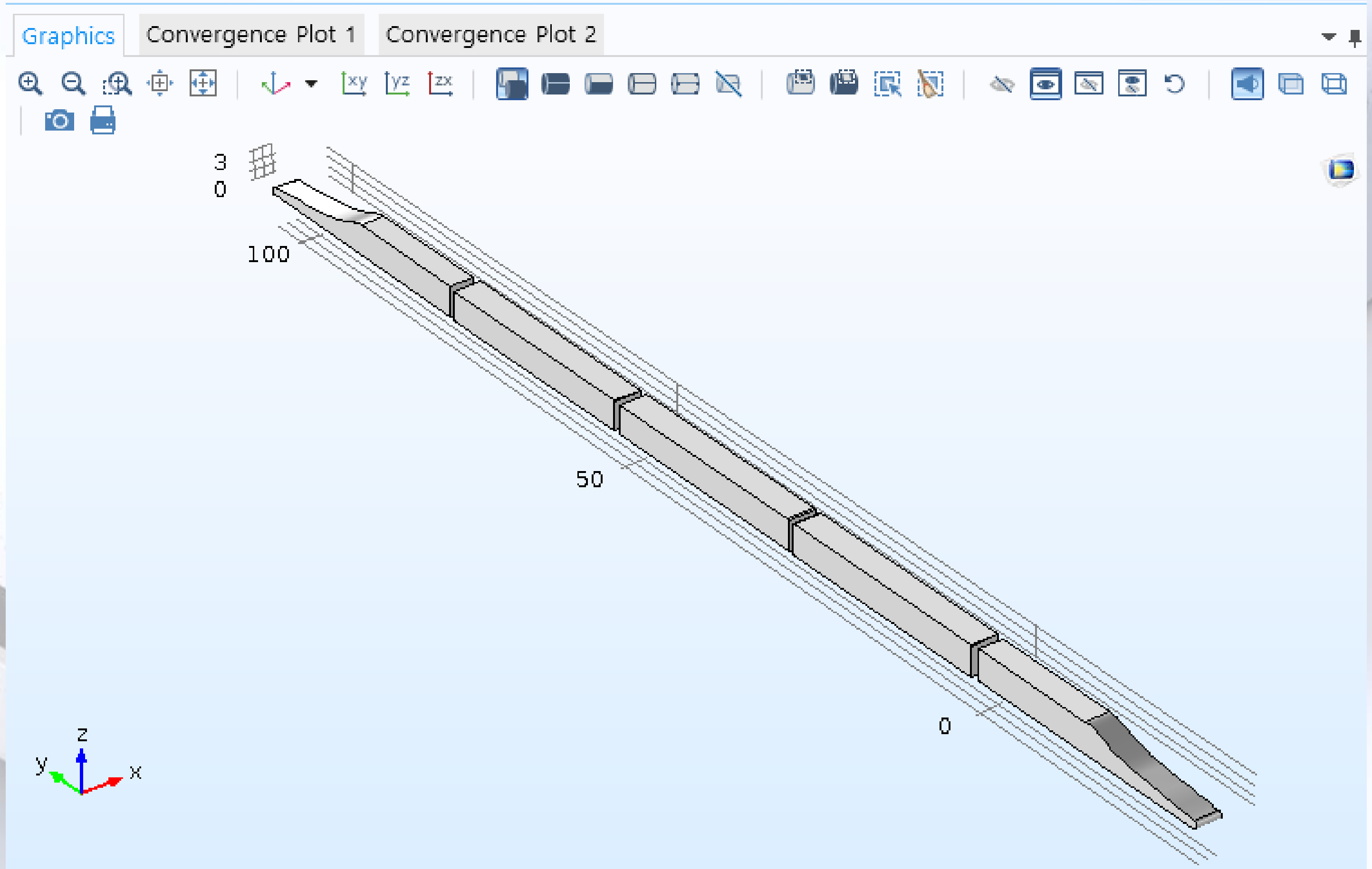


$$Re = \frac{\rho V D}{\mu}$$

$$= \frac{1.2044*30*3}{1.814*10^{-5}}$$

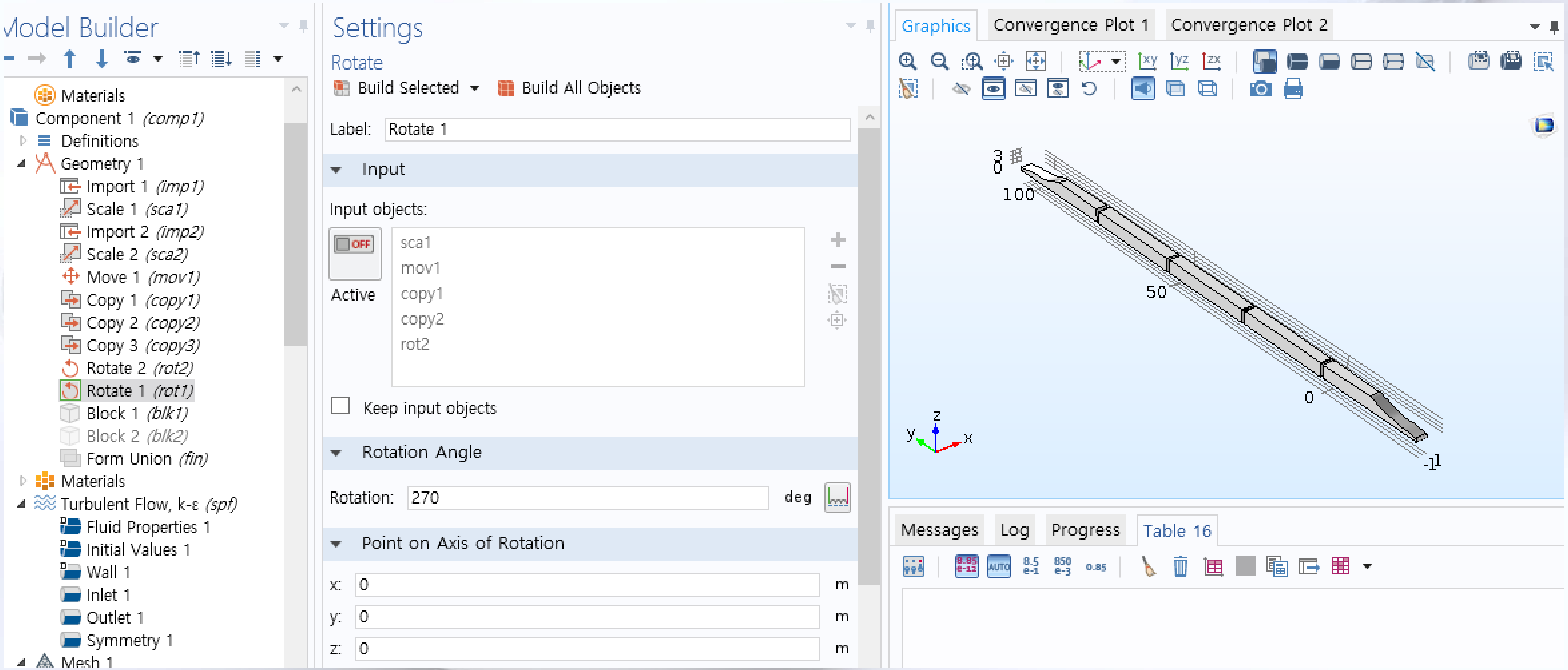
$$\approx 6*10^5$$

모델링 – 공기저항

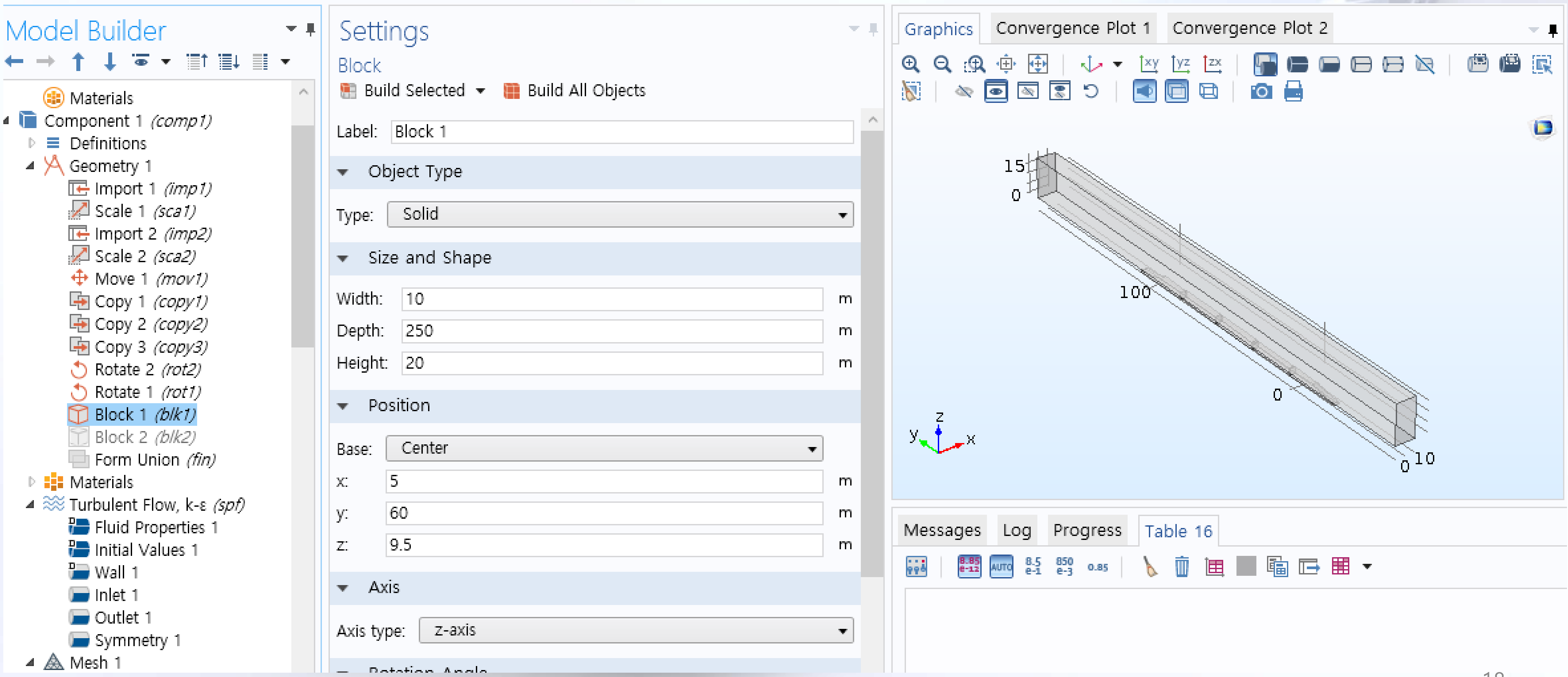


Graphics
Convergence Plot 1
Convergence Plot 2
3
0
100
50
0
z
y
x

모델링 – 공기저항

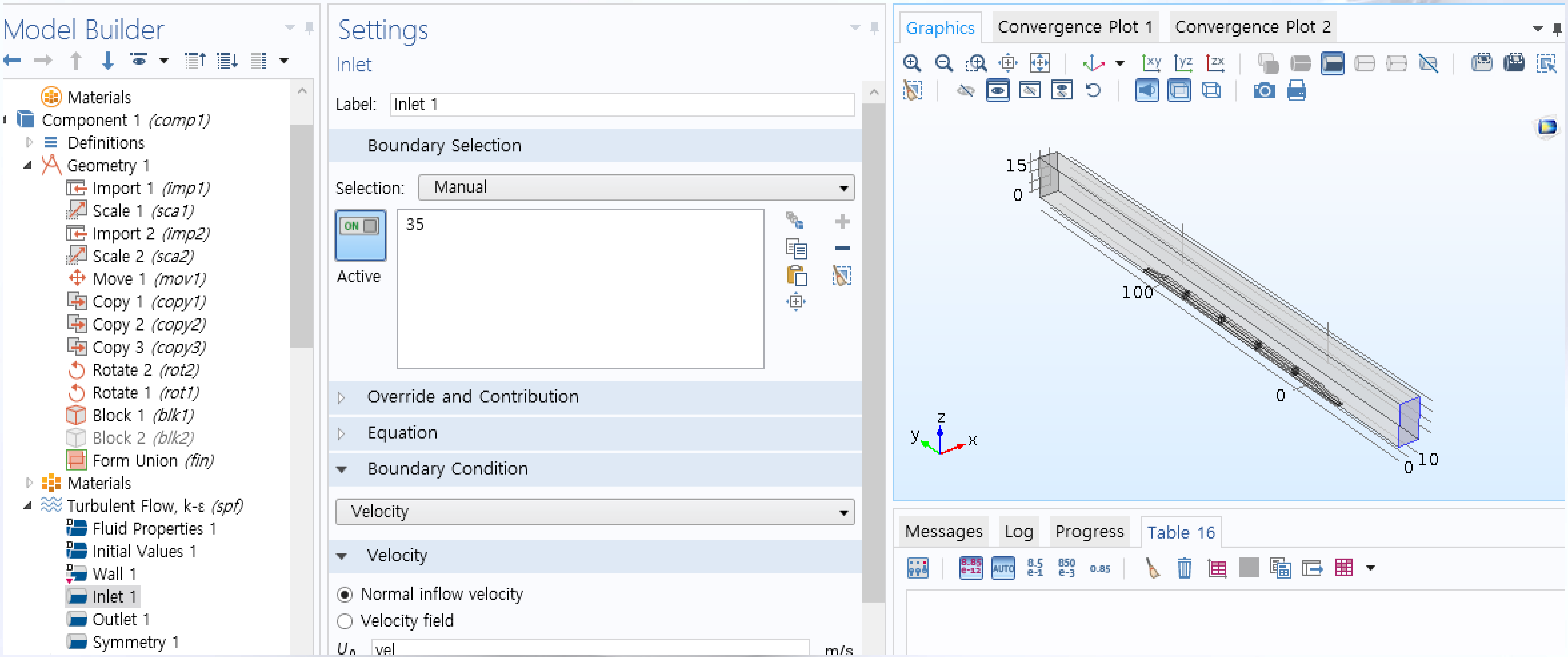

Model Builder
Materials
Component 1 (comp1)
Definitions
Geometry 1
Import 1 (imp1)
Scale 1 (sca1)
Import 2 (imp2)
Scale 2 (sca2)
Move 1 (mov1)
Copy 1 (copy1)
Copy 2 (copy2)
Copy 3 (copy3)
Rotate 2 (rot2)
Rotate 1 (rot1)
Block 1 (blk1)
Block 2 (blk2)
Form Union (fin)
Materials
Turbulent Flow, k-ε (spf)
Fluid Properties 1
Initial Values 1
Wall 1
Inlet 1
Outlet 1
Symmetry 1
Mesh 1
Settings
Rotate
Build Selected
Build All Objects
Label: Rotate 1
Input
Input objects:
OFF
Active
sca1
mov1
copy1
copy2
rot2
Keep input objects
Rotation Angle
Rotation: 270 deg
Point on Axis of Rotation
x: 0 m
y: 0 m
z: 0 m
Graphics
Convergence Plot 1
Convergence Plot 2
100
50
0
z
y
x
Messages
Log
Progress
Table 16

모델링 – 공기저항

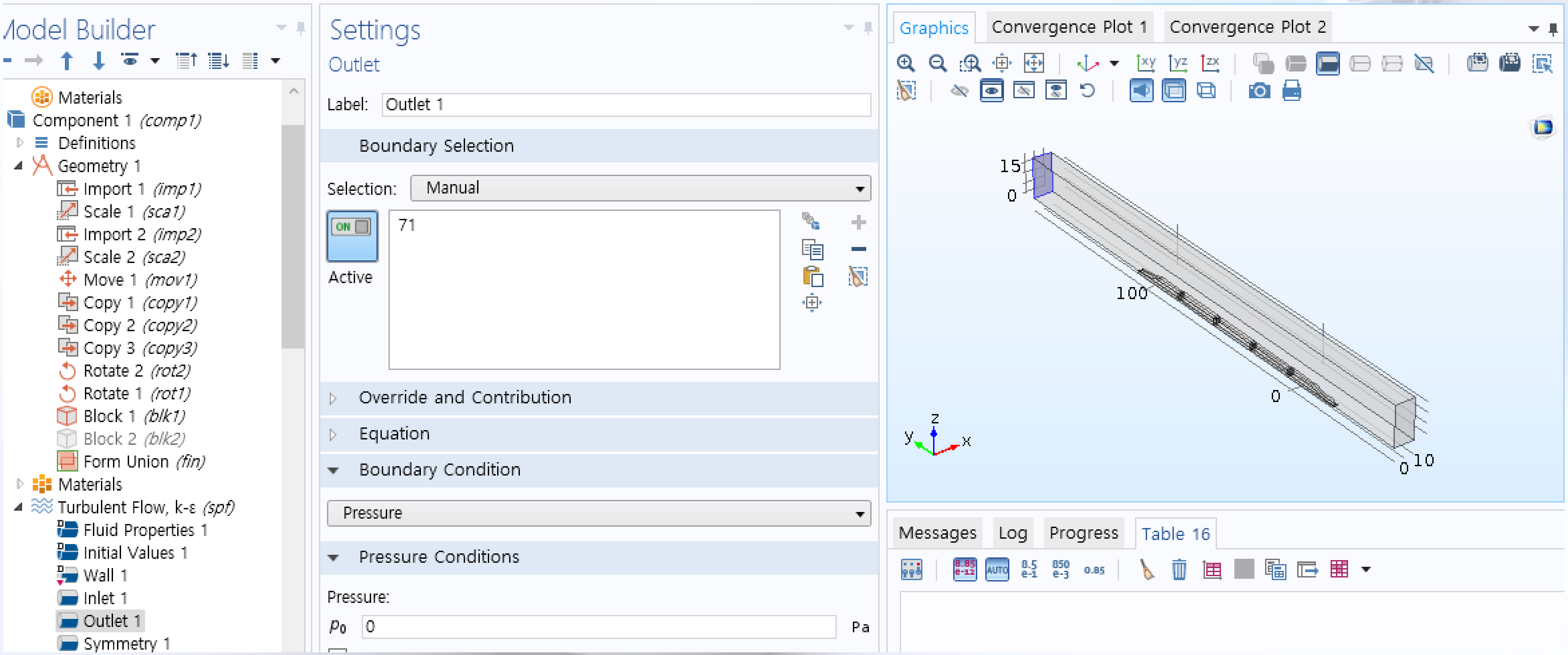


Model Builder
Materials
Component 1 (comp1)
Definitions
Geometry 1
Import 1 (imp1)
Scale 1 (sca1)
Import 2 (imp2)
Scale 2 (sca2)
Move 1 (mov1)
Copy 1 (copy1)
Copy 2 (copy2)
Copy 3 (copy3)
Rotate 2 (rot2)
Rotate 1 (rot1)
Block 1 (blk1)
Block 2 (blk2)
Form Union (fin)
Materials
Turbulent Flow, k-ε (spf)
Fluid Properties 1
Initial Values 1
Wall 1
Inlet 1
Outlet 1
Symmetry 1
Mesh 1
Settings
Block
Build Selected
Build All Objects
Label: Block 1
Object Type
Type: Solid
Size and Shape
Width: 10 m
Depth: 250 m
Height: 20 m
Position
Base: Center
x: 5 m
y: 60 m
z: 9.5 m
Axis
Axis type: z-axis
Graphics
Convergence Plot 1
Convergence Plot 2
15
0
100
0
0
10
z
y
x
Messages
Log
Progress
Table 16

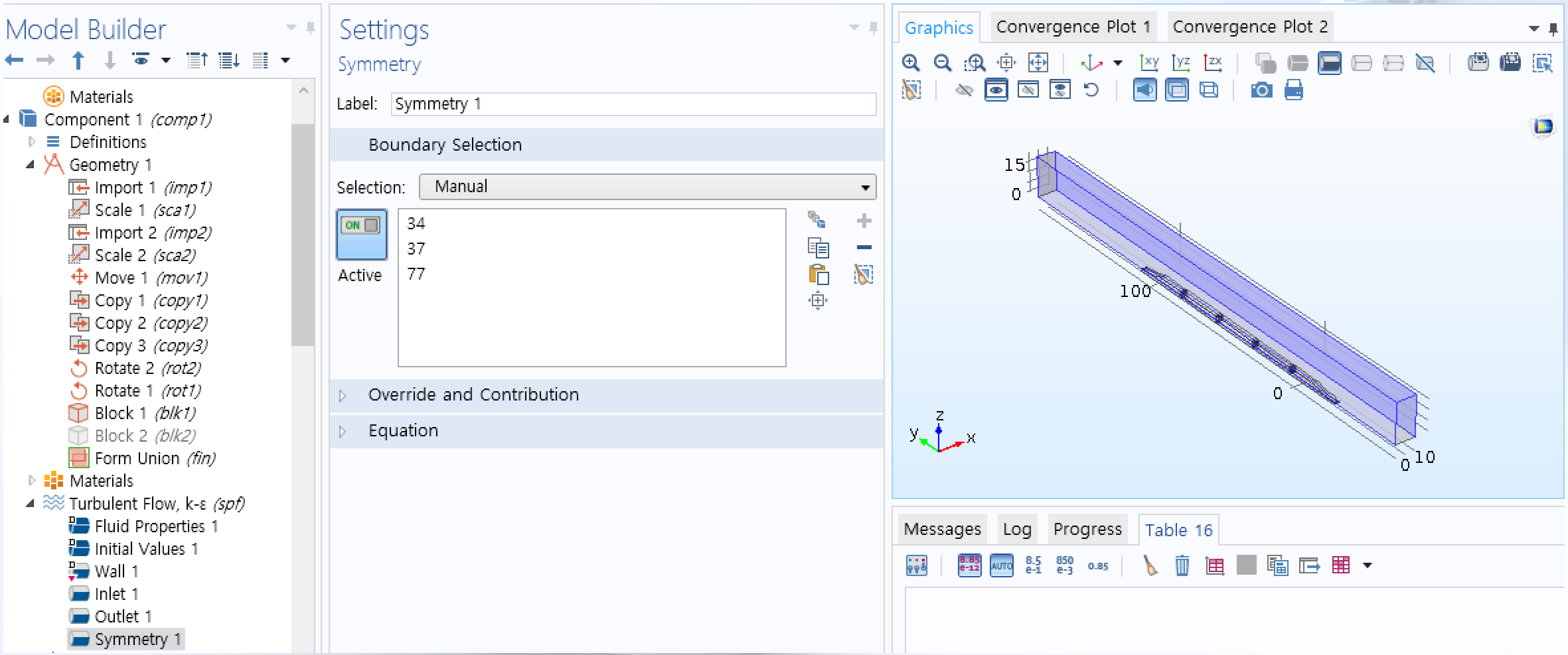
모델링 – 공기저항


Model Builder
Materials
Component 1 (comp1)
Definitions
Geometry 1
Import 1 (imp1)
Scale 1 (sca1)
Import 2 (imp2)
Scale 2 (sca2)
Move 1 (mov1)
Copy 1 (copy1)
Copy 2 (copy2)
Copy 3 (copy3)
Rotate 2 (rot2)
Rotate 1 (rot1)
Block 1 (blk1)
Block 2 (blk2)
Form Union (fin)
Materials
Turbulent Flow, k-ε (spf)
Fluid Properties 1
Initial Values 1
Wall 1
Inlet 1
Outlet 1
Symmetry 1
Settings
Inlet
Label: Inlet 1
Boundary Selection
Selection: Manual
ON
Active
35
Override and Contribution
Equation
Boundary Condition
Velocity
Velocity
Normal inflow velocity
Velocity field
U0 vel m/s
Graphics
Convergence Plot 1
Convergence Plot 2
15
0
100
0
0
10
z
y
x
Messages
Log
Progress
Table 16

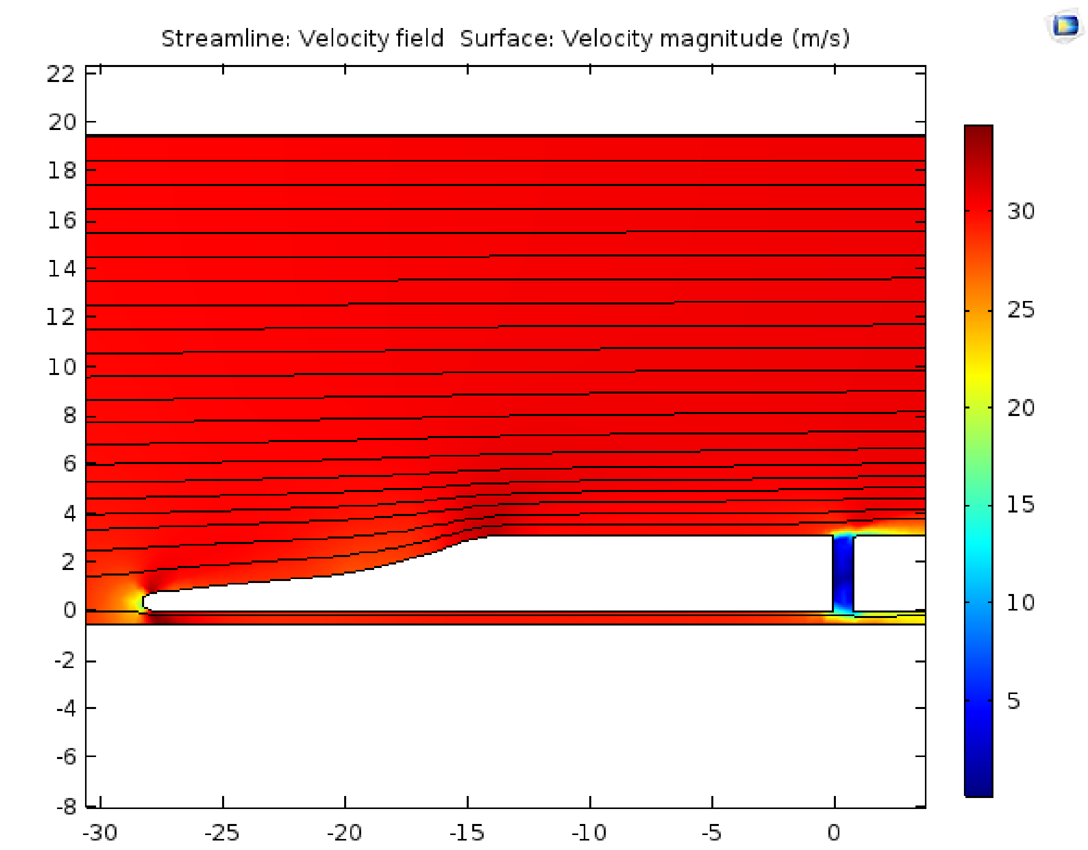
모델링 – 공기저항


Model Builder
Materials
Component 1 (comp1)
Definitions
Geometry 1
Import 1 (imp1)
Scale 1 (sca1)
Import 2 (imp2)
Scale 2 (sca2)
Move 1 (mov1)
Copy 1 (copy1)
Copy 2 (copy2)
Copy 3 (copy3)
Rotate 2 (rot2)
Rotate 1 (rot1)
Block 1 (blk1)
Block 2 (blk2)
Form Union (fin)
Materials
Turbulent Flow, k-ε (spf)
Fluid Properties 1
Initial Values 1
Wall 1
Inlet 1
Outlet 1
Symmetry 1
Settings
Outlet
Label: Outlet 1
Boundary Selection
Selection: Manual
71
Active
Override and Contribution
Equation
Boundary Condition
Pressure
Pressure Conditions
Pressure:
p0 0 Pa
Graphics
Convergence Plot 1
Convergence Plot 2
Messages
Log
Progress
Table 16

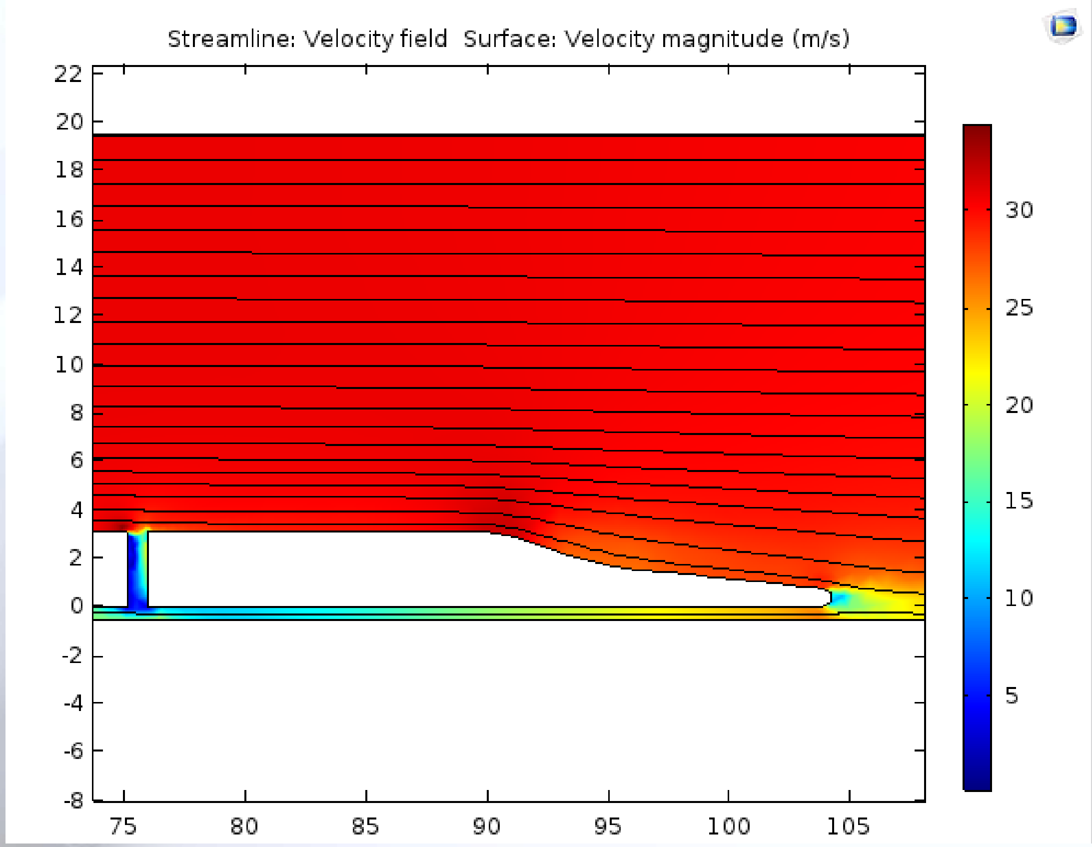
모델링 – 공기저항


Model Builder
Materials
Component 1 (comp1)
Definitions
Geometry 1
Import 1 (imp1)
Scale 1 (sca1)
Import 2 (imp2)
Scale 2 (sca2)
Move 1 (mov1)
Copy 1 (copy1)
Copy 2 (copy2)
Copy 3 (copy3)
Rotate 2 (rot2)
Rotate 1 (rot1)
Block 1 (blk1)
Block 2 (blk2)
Form Union (fin)
Materials
Turbulent Flow, k-ε (spf)
Fluid Properties 1
Initial Values 1
Wall 1
Inlet 1
Outlet 1
Symmetry 1
Settings
Symmetry
Label: Symmetry 1
Boundary Selection
Selection: Manual
ON
Active
34
37
77
Override and Contribution
Equation
Graphics
Convergence Plot 1
Convergence Plot 2
15
0
100
0
0
10
z
y
x
Messages
Log
Progress
Table 16

모델링 – 공기저항

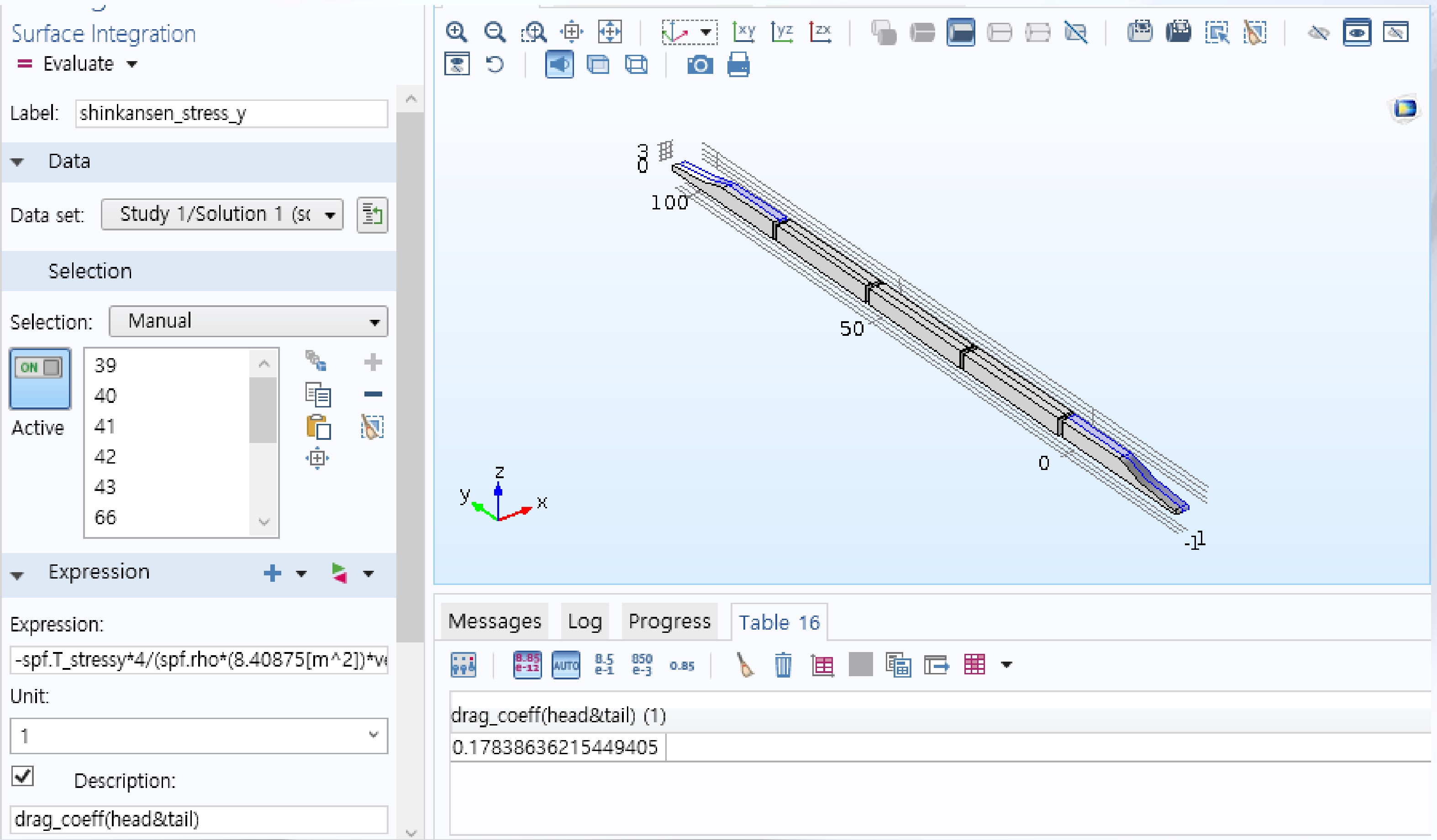


Streamline: Velocity field Surface: Velocity magnitude (m/s)
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-30
-25
-20
-15
-10
-5
0
30
25
20
15
10
5



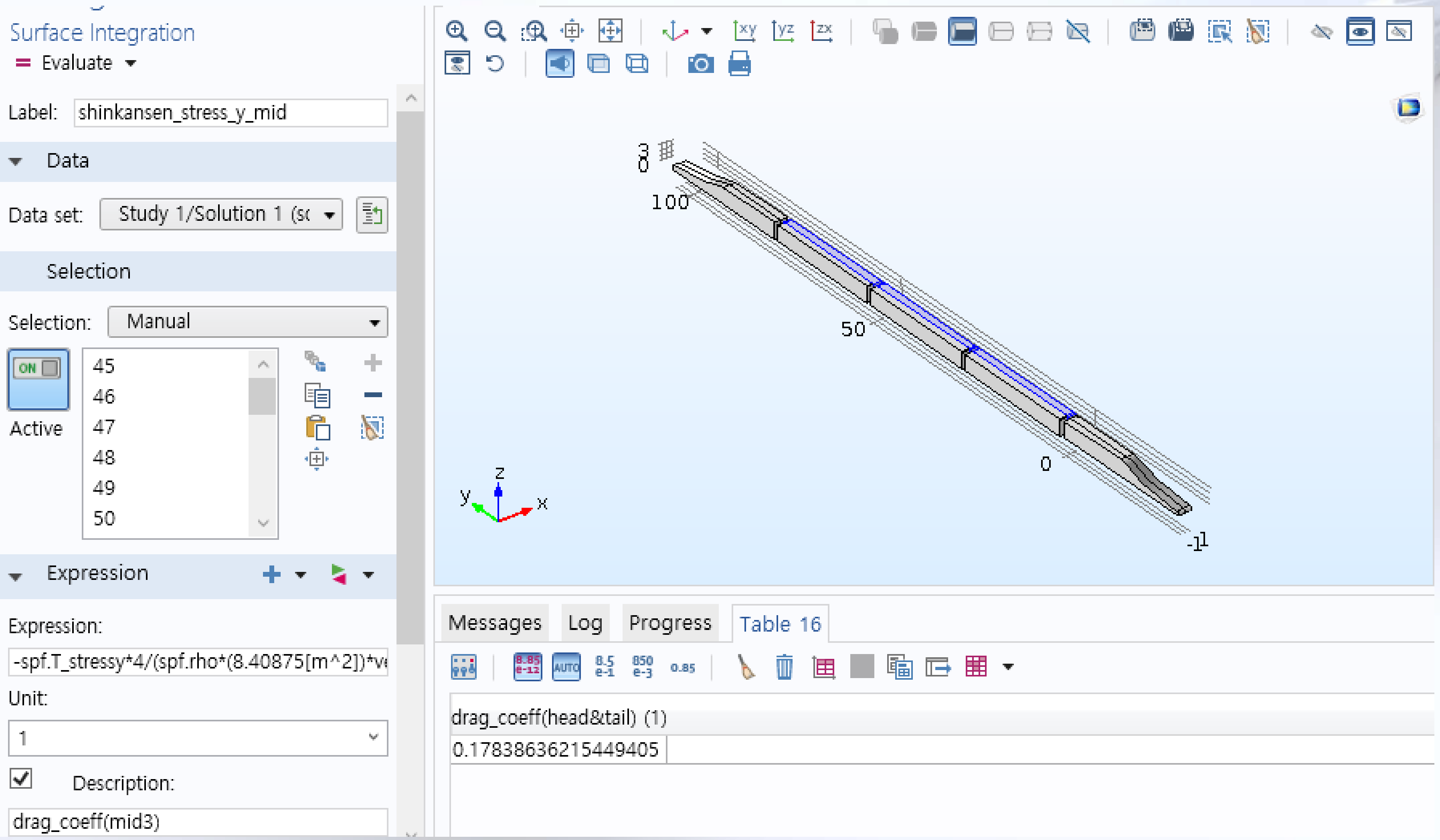
Streamline: Velocity field Surface: Velocity magnitude (m/s)
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
75
80
85
90
95
100
105
30
25
20
15
10
5

모델링 – 공기저항



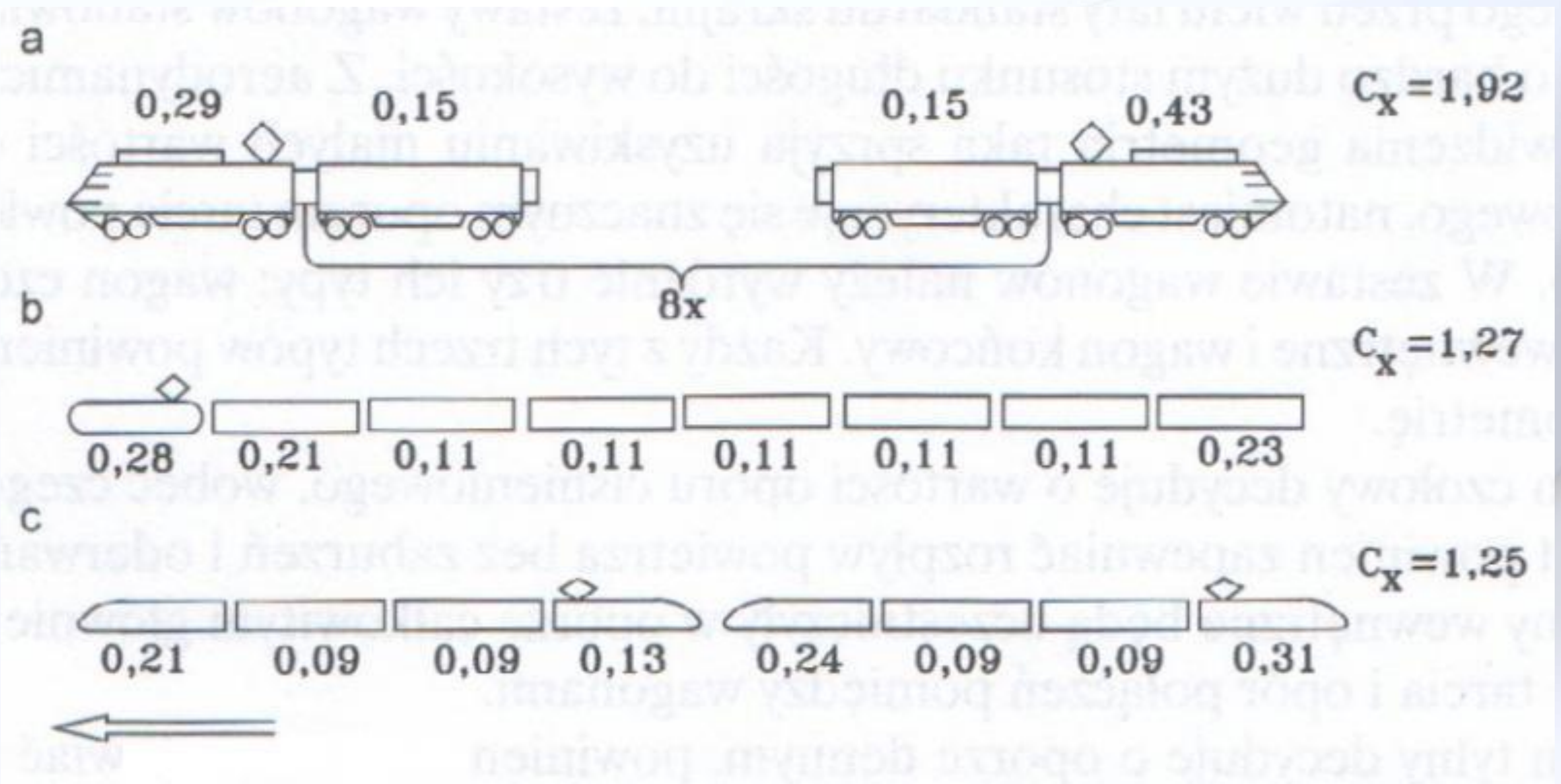
Surface Integration
Evaluate
Label: shinkansen_stress_y
Data
Data set: Study 1/Solution 1 (sc
Selection
Selection: Manual
ON
Active
39
40
41
42
43
66
Expression
Expression:
-spf.T_stressy*4/(spf.rho*(8.40875[m^2])*ve
Unit:
1
Description:
drag_coeff(head&tail)
100
50
0
z
y
x
Messages
Log
Progress
Table 16
drag_coeff(head&tail) (1)
0.17838636215449405

모델링 – 공기저항



Surface Integration
Evaluate
Label: shinkansen_stress_y_mid
Data
Data set: Study 1/Solution 1 (sc
Selection
Selection: Manual
ON
Active
45
46
47
48
49
50
Expression
Expression:
-spf.T_stressy*4/(spf.rho*(8.40875[m^2])*ve
Unit:
1
Description:
drag_coeff(mid3)
100
50
0
z
y
x
Messages
Log
Progress
Table 16
drag_coeff(head&tail) (1)
0.17838636215449405

모델링 – 공기저항



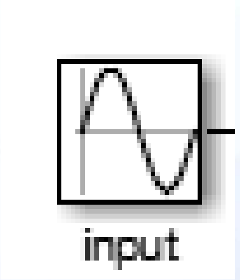
drag_coeff(head&tail) (1)
0.17838636215449405

drag_coeff(mid3) (1)
0.38037568450711035

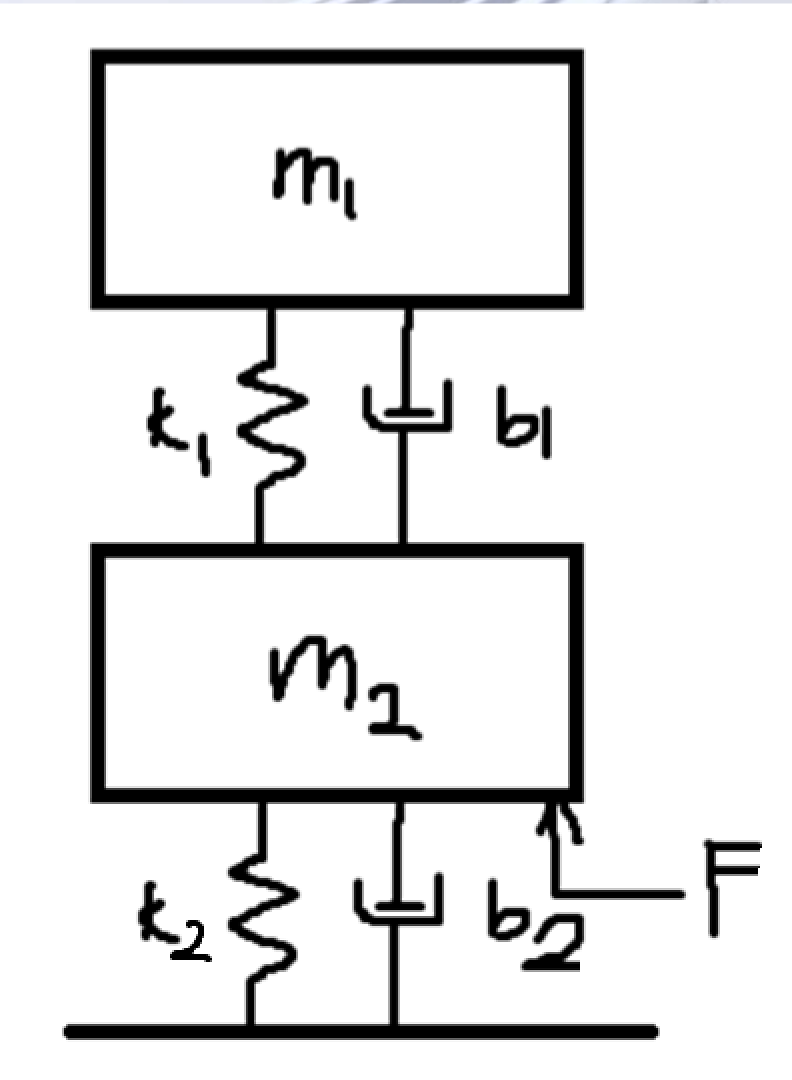
$$C_d \approx 1.572$$

1/52 모델

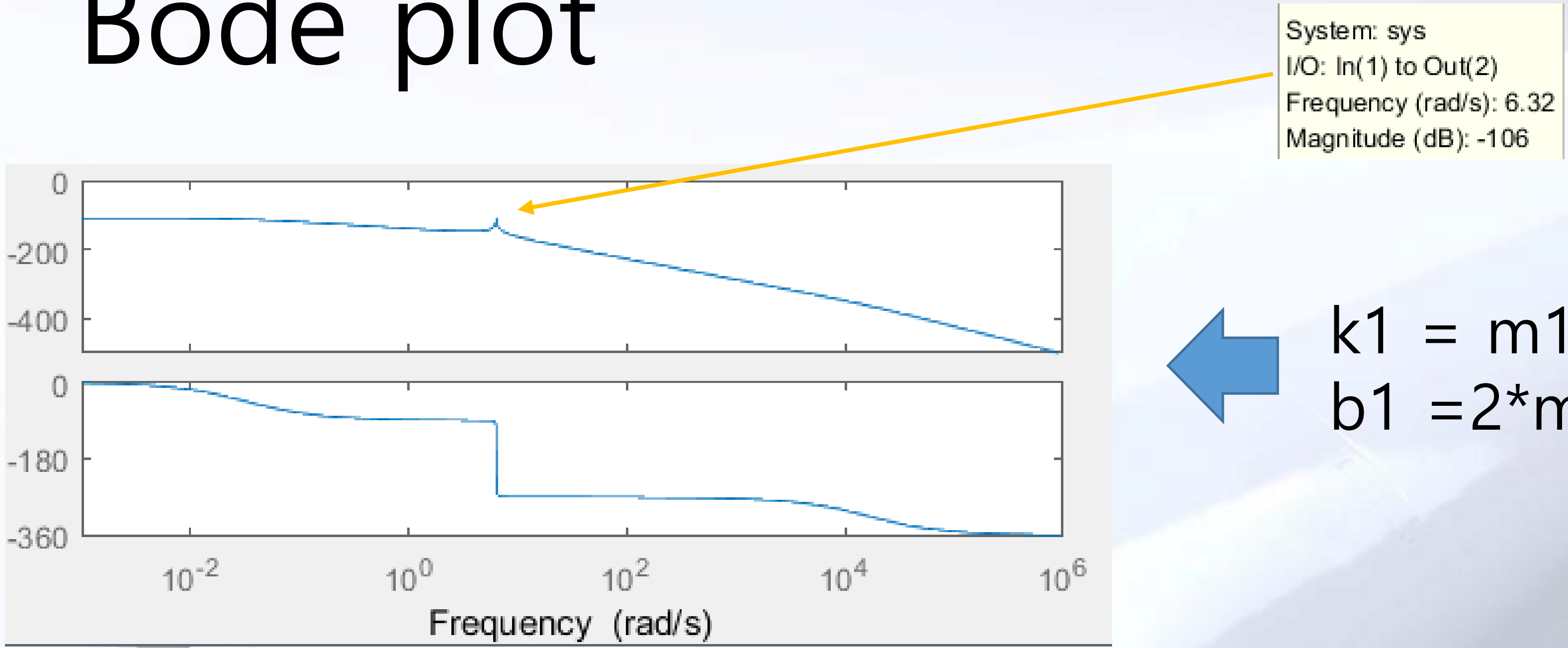
- 입력 = 부상력 ripple
- $\mathrm{F} = \ 330000/52 * \cos(w * t)$
- $w = 2\pi * f = v * \frac{1000}{3600}/0.45$(rad/sec)



- 차량의 무게(m1) = 270ton/52
- 대차의 무게(m2) = 30ton/52
- k2 = 27000k/52
- b2 = 500000k/52

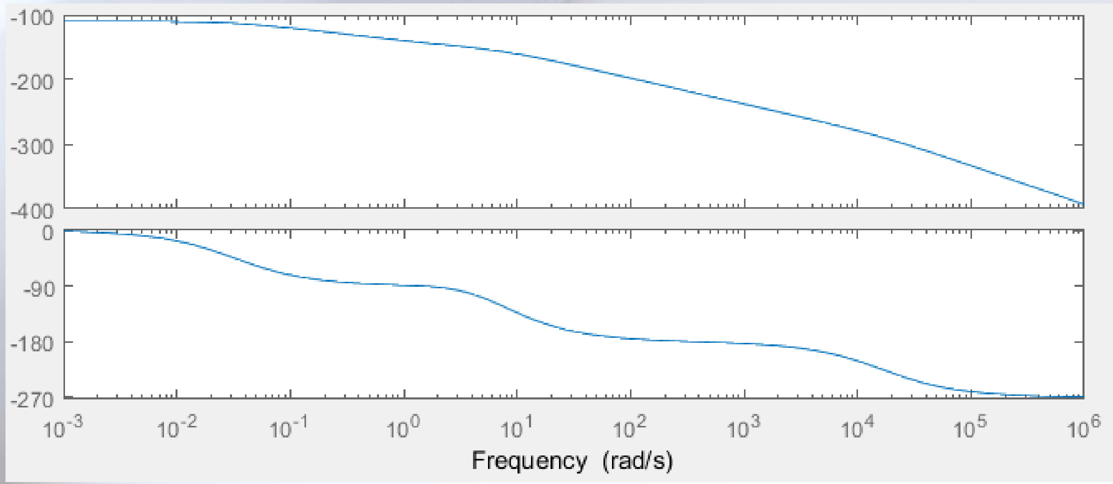


Bode plot



k1 = m1*40/52
b1 =2*m1*sqrt(k1/m1)*0/52

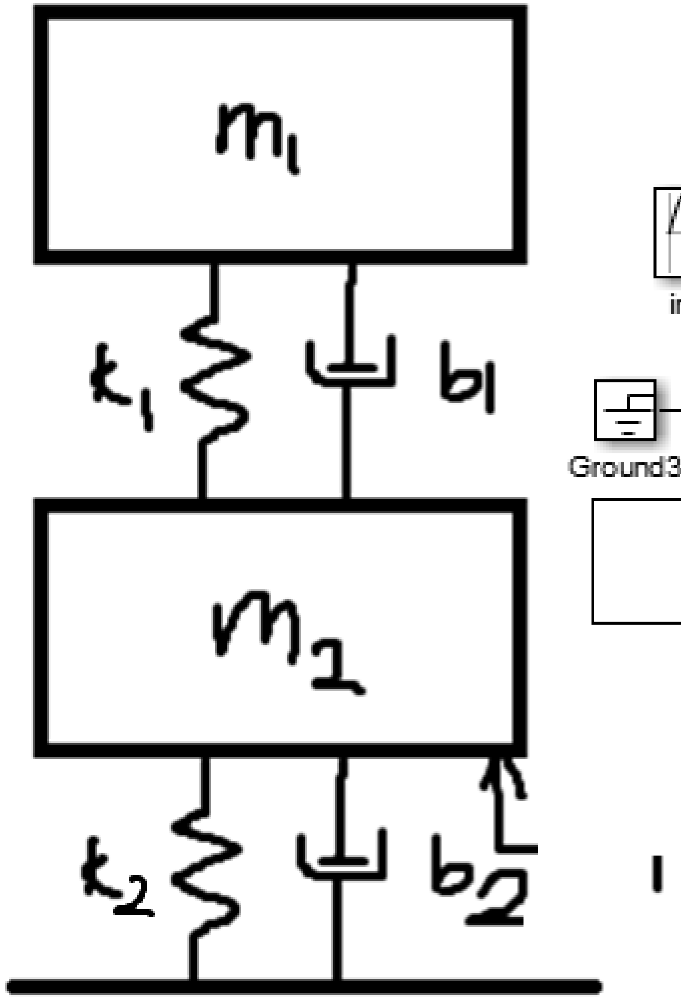
k1 = m1*40/52
b1 =2*m1*sqrt(k1/m1)*1/52

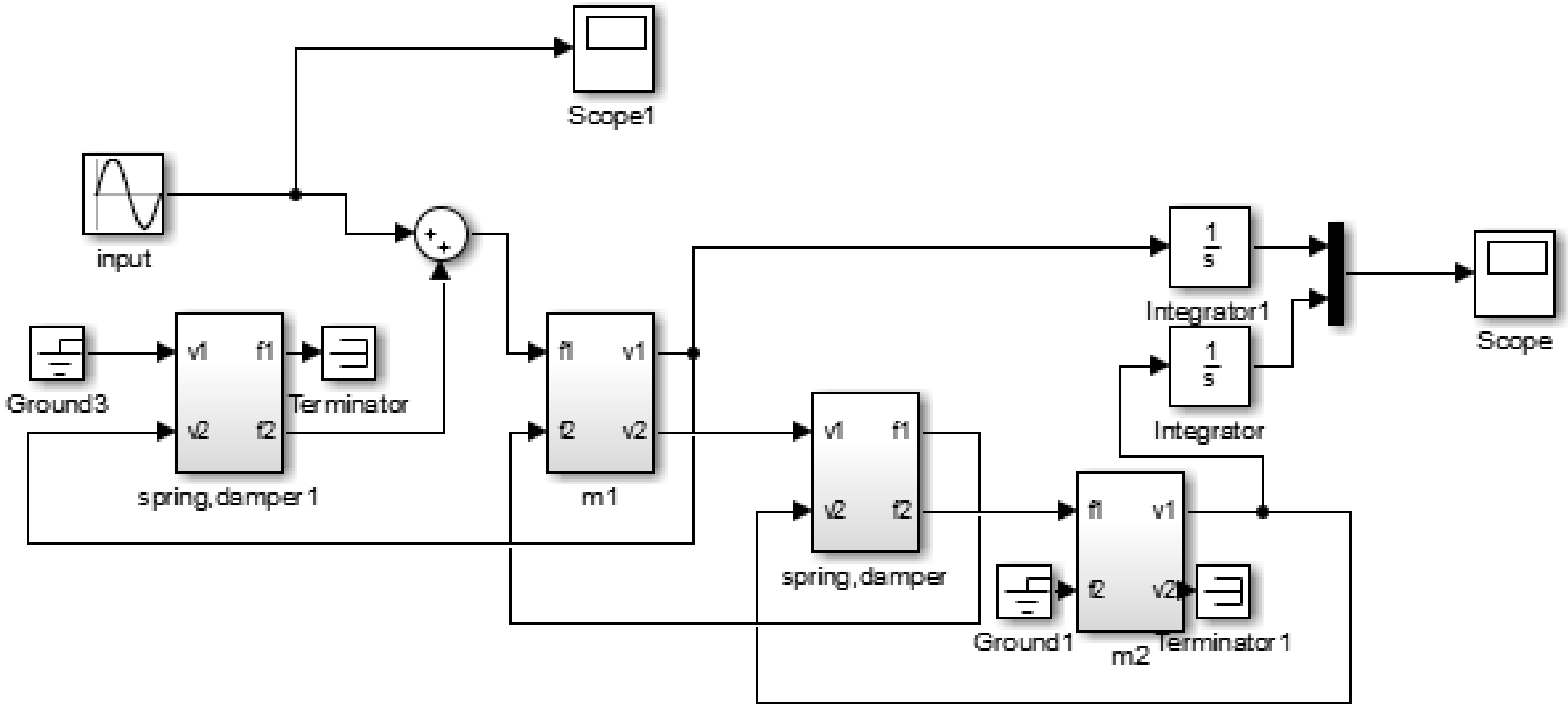


$$\zeta = \text{damping ratio} = \frac{\text{actual damping value}}{\text{critical damping value}} = \frac{b}{2\sqrt{km}}$$

Critically damped ($\zeta = 1$)

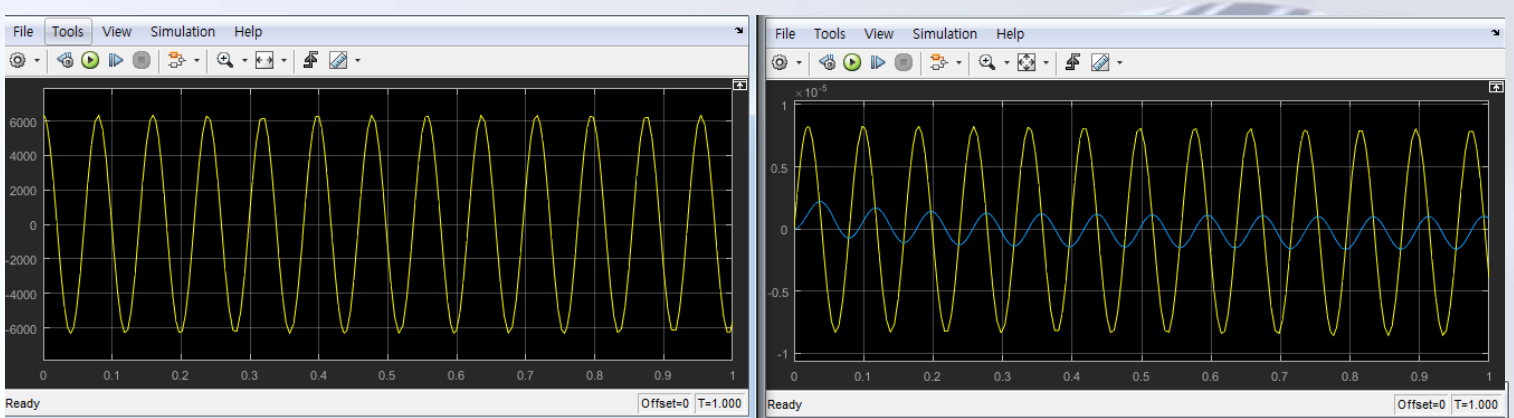
Simulink


m1
k1
b1
m2
k2
b2


Scope1
input
Ground3
v1
v2
f1
f2
Terminator
spring,damper1
m1
1/s
Integrator1
Integrator
Scope
spring,damper
Ground1
m2
Terminator1

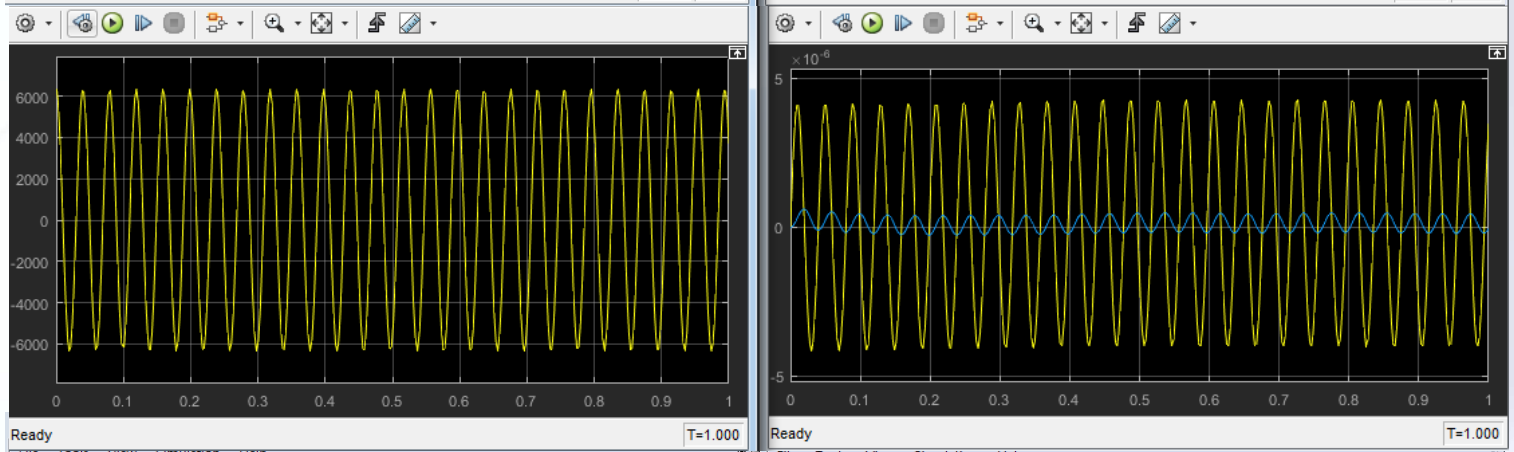
- V = 128

대차:7.5*e-6m
차체:2.5*e-6m



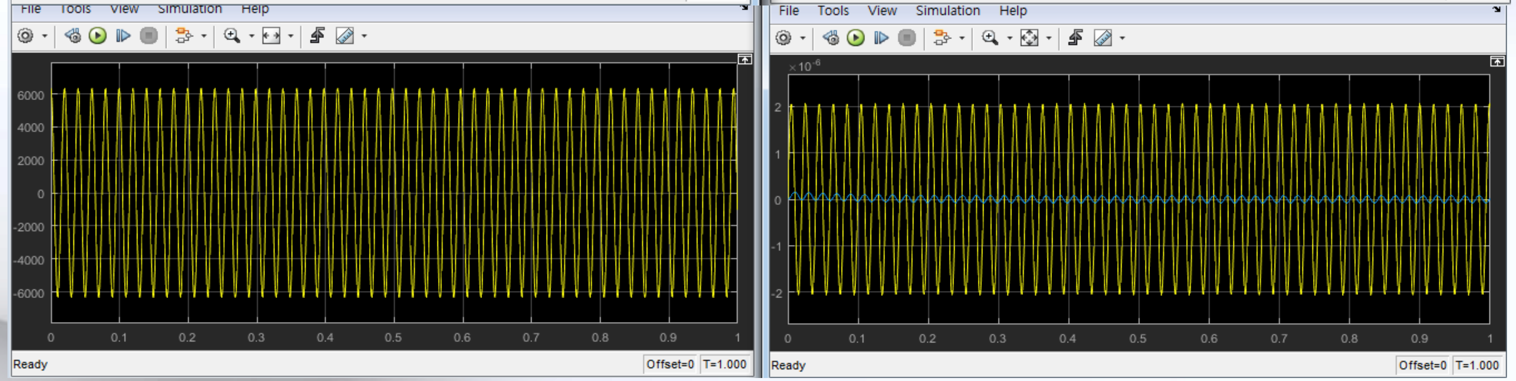
- V = 256

대차:4*e-6m
차체:0.5*e-6m

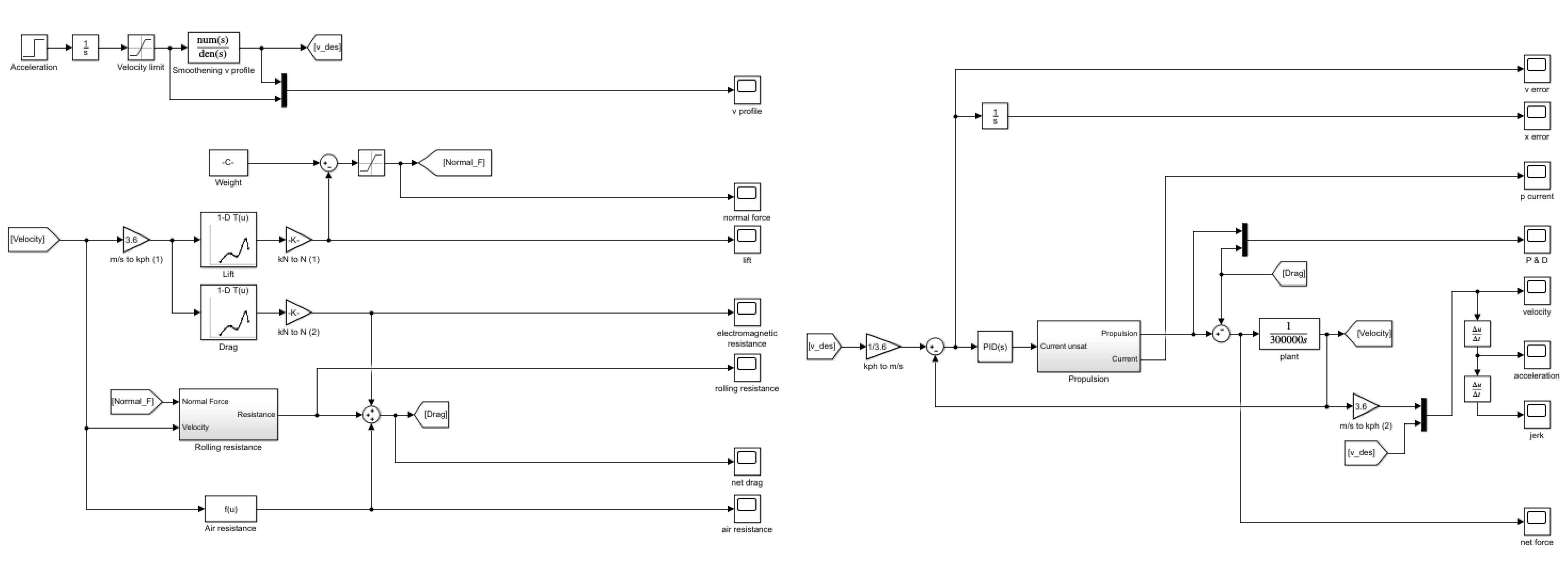


- V = 512

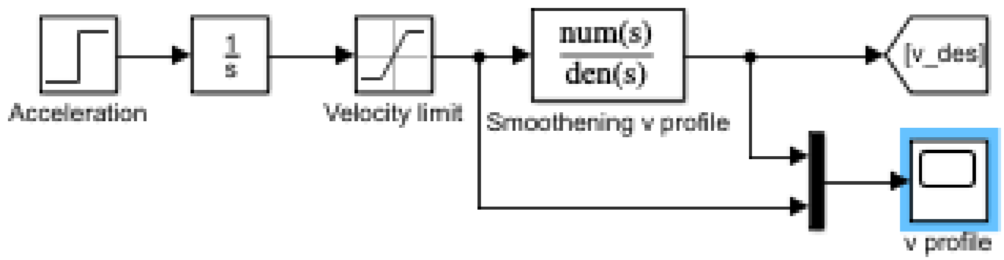
대차:2*e-6m
차체:0.1*e-6m

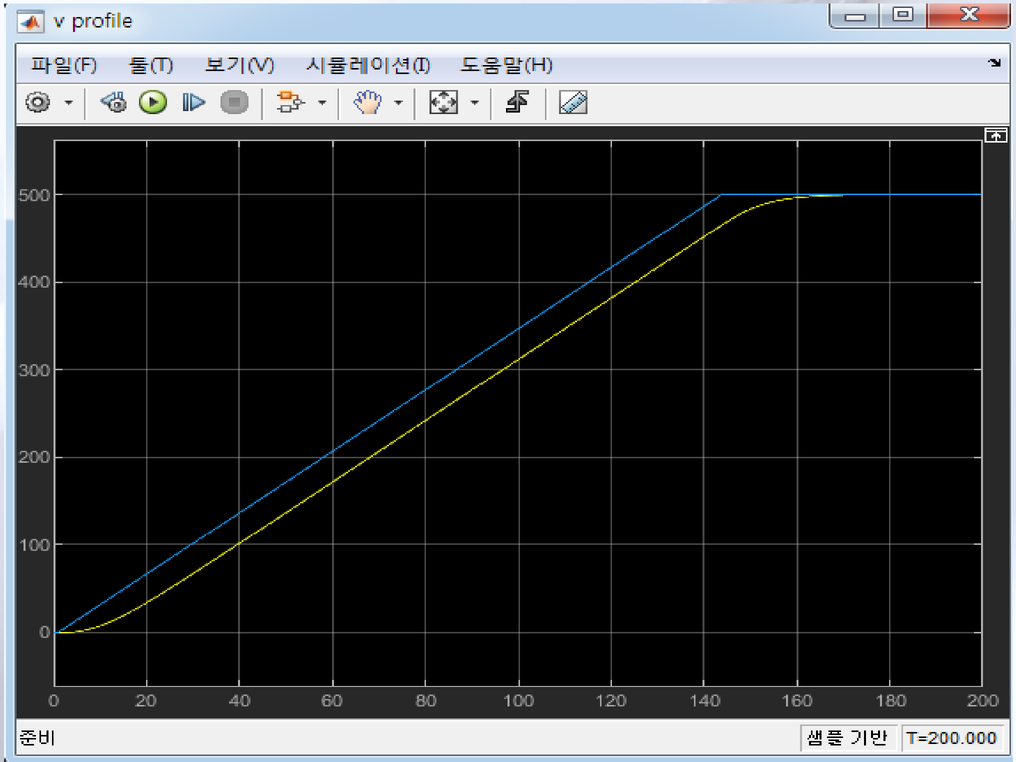


Complete Design

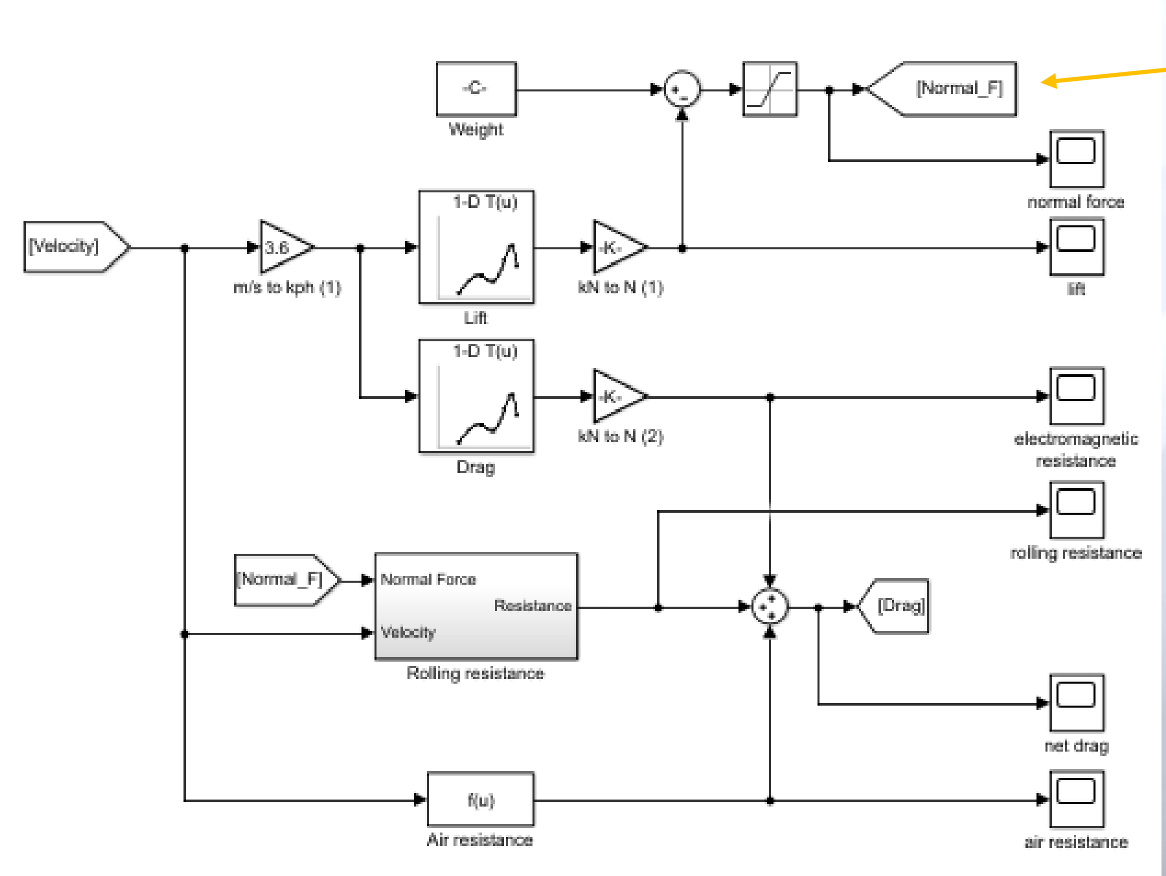


Desired velocity

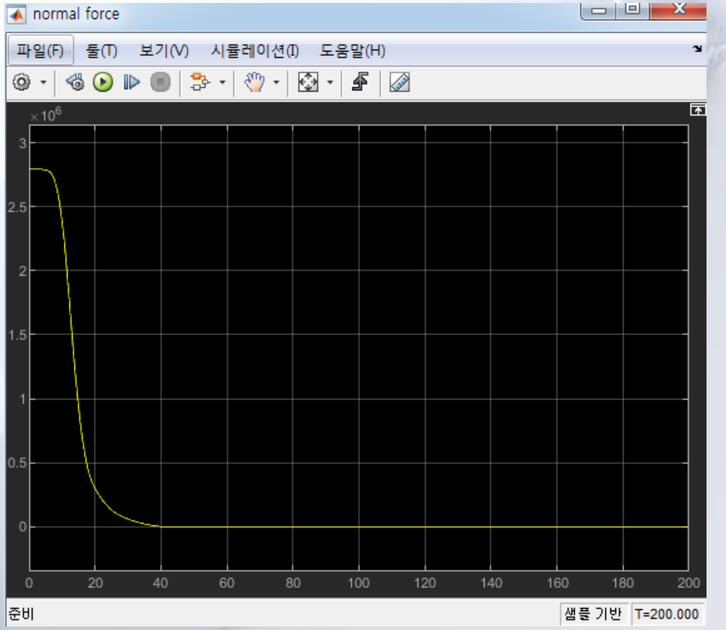




수직항력

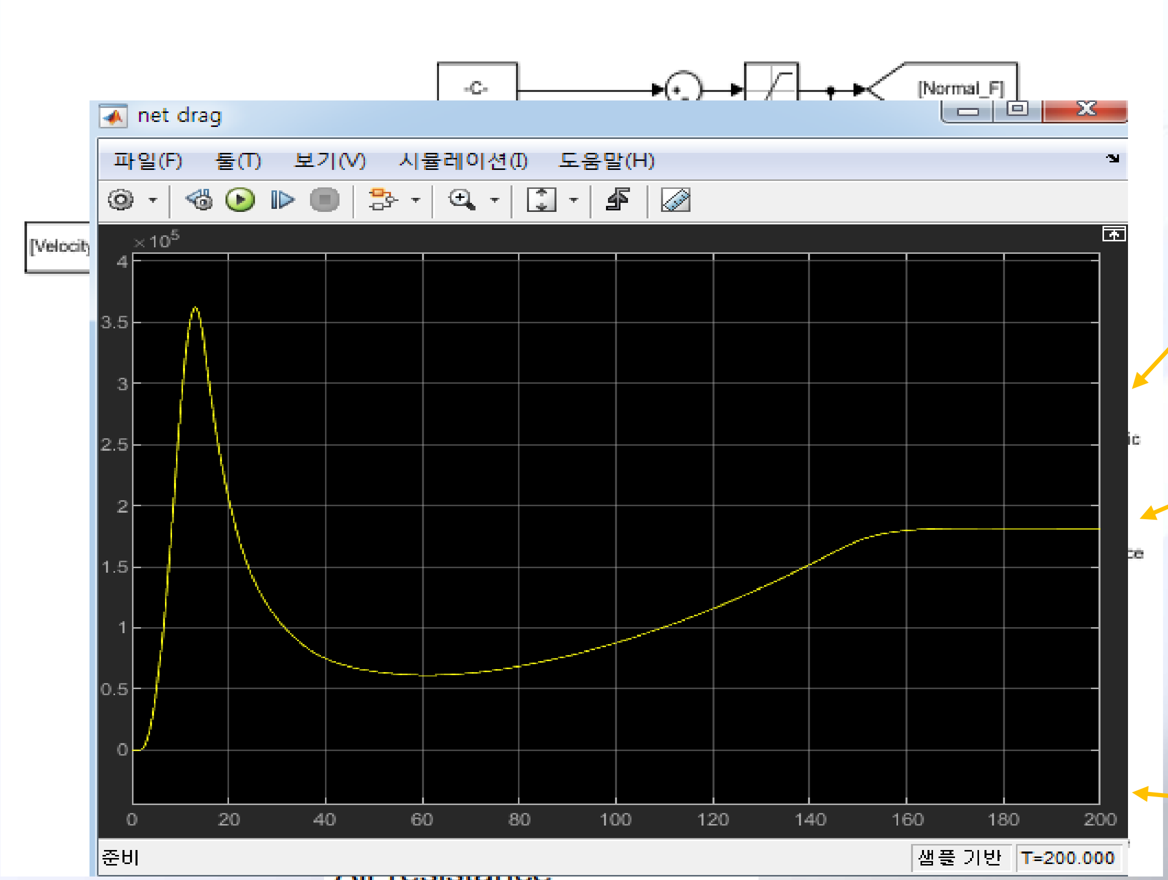


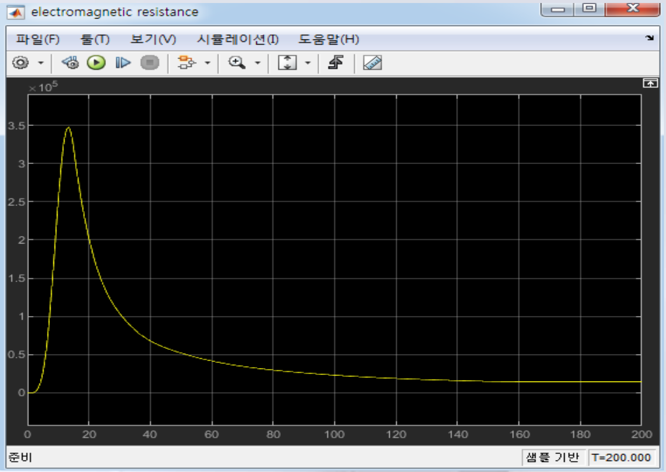
-C-
Weight
[Normal_F]
normal force
[Velocity]
3.6
m/s to kph (1)
1-D T(u)
Lift
-K-
kN to N (1)
lift
1-D T(u)
Drag
-K-
kN to N (2)
electromagnetic resistance
rolling resistance
[Normal_F]
Normal Force
Resistance
Velocity
Rolling resistance
[Drag]
net drag
f(u)
Air resistance
air resistance

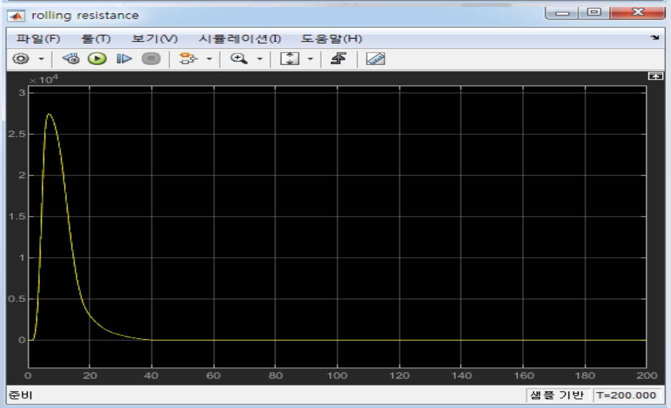


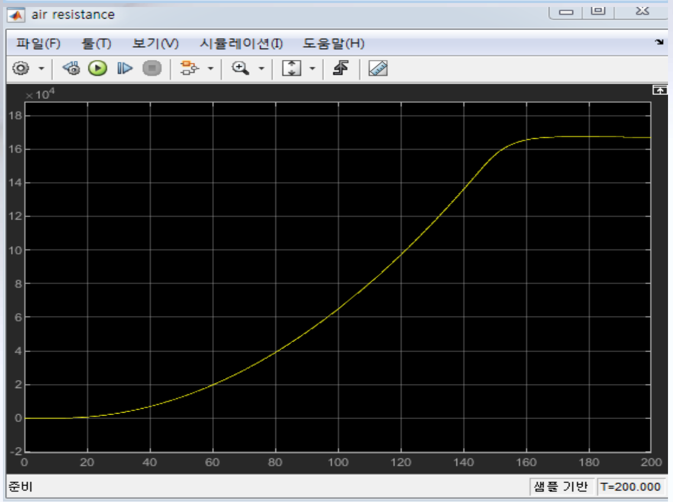
normal force
파일(F) 툴(T) 보기(V) 시뮬레이션(I) 도움말(H)
$\times 10^6$
3
2.5
2
1.5
1
0.5
0
0 20 40 60 80 100 120 140 160 180 200
준비
샘플 기반
T=200.000

저항력









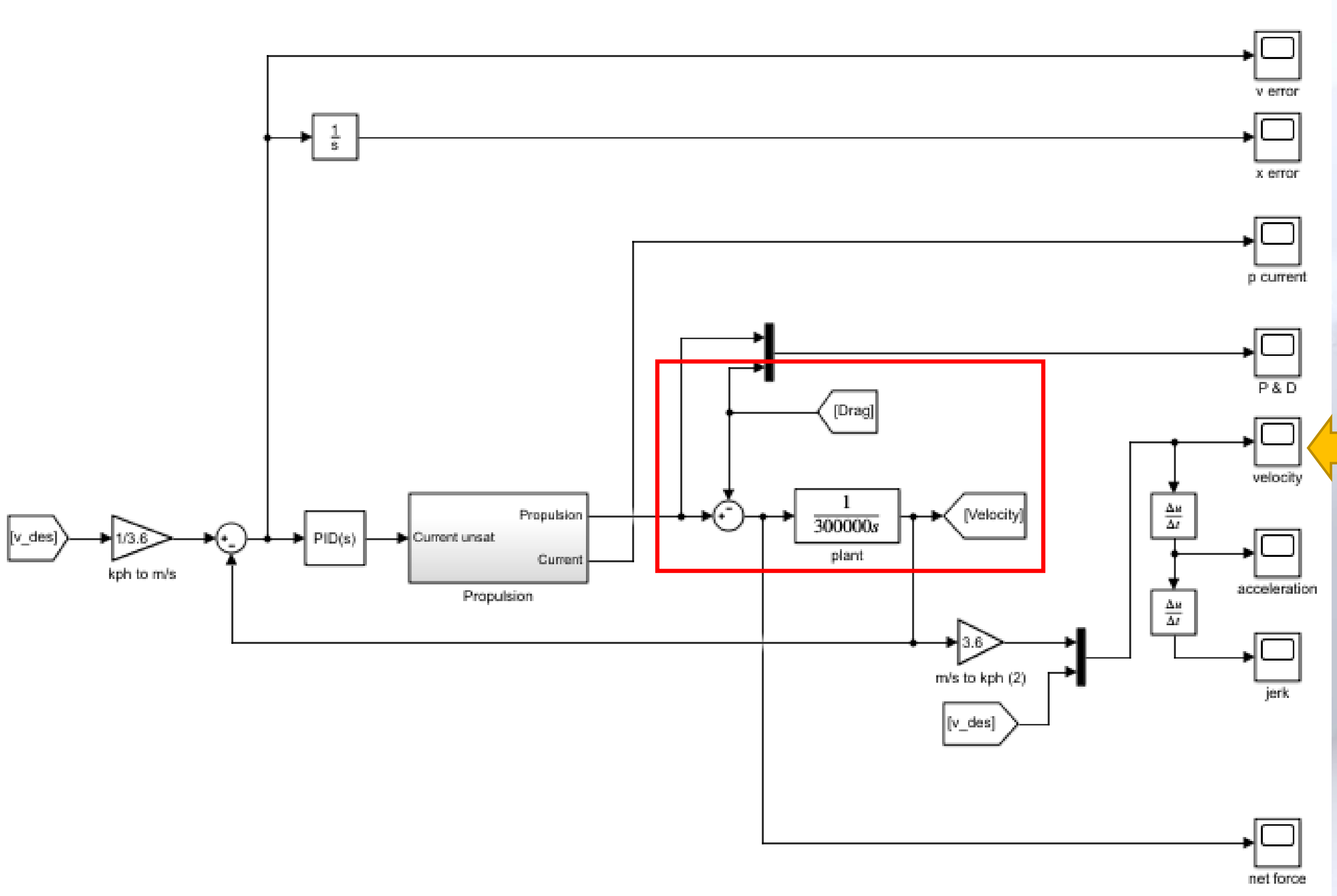
Rolling resistance

$$F_{roll} = \mu_r m_{body} g$$

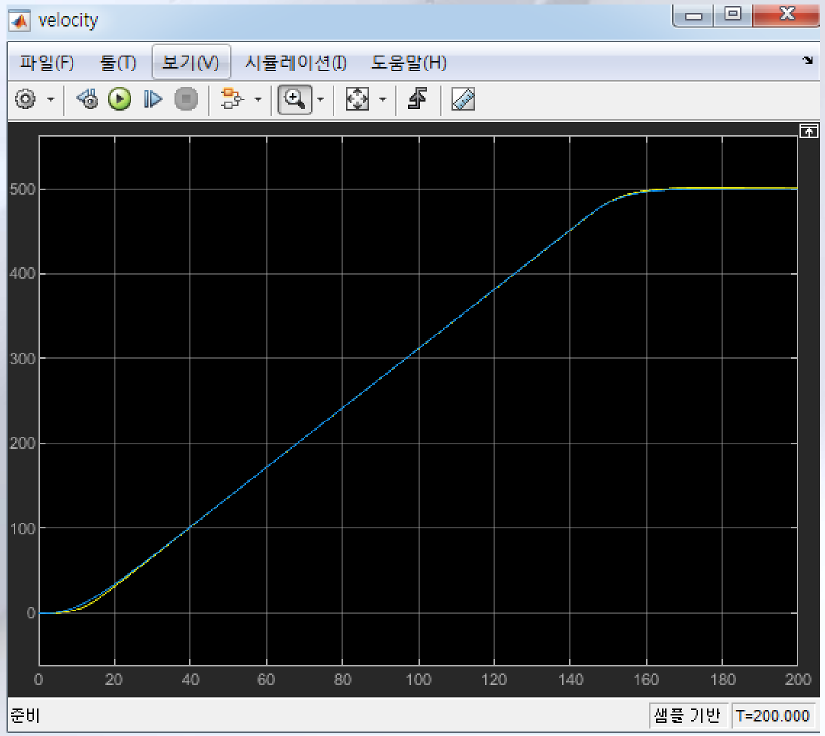
Air resistance

$$F_{air} = \frac{1}{2} C_d A_{fr} \rho_{air} V_{veh}^2$$

Velocity

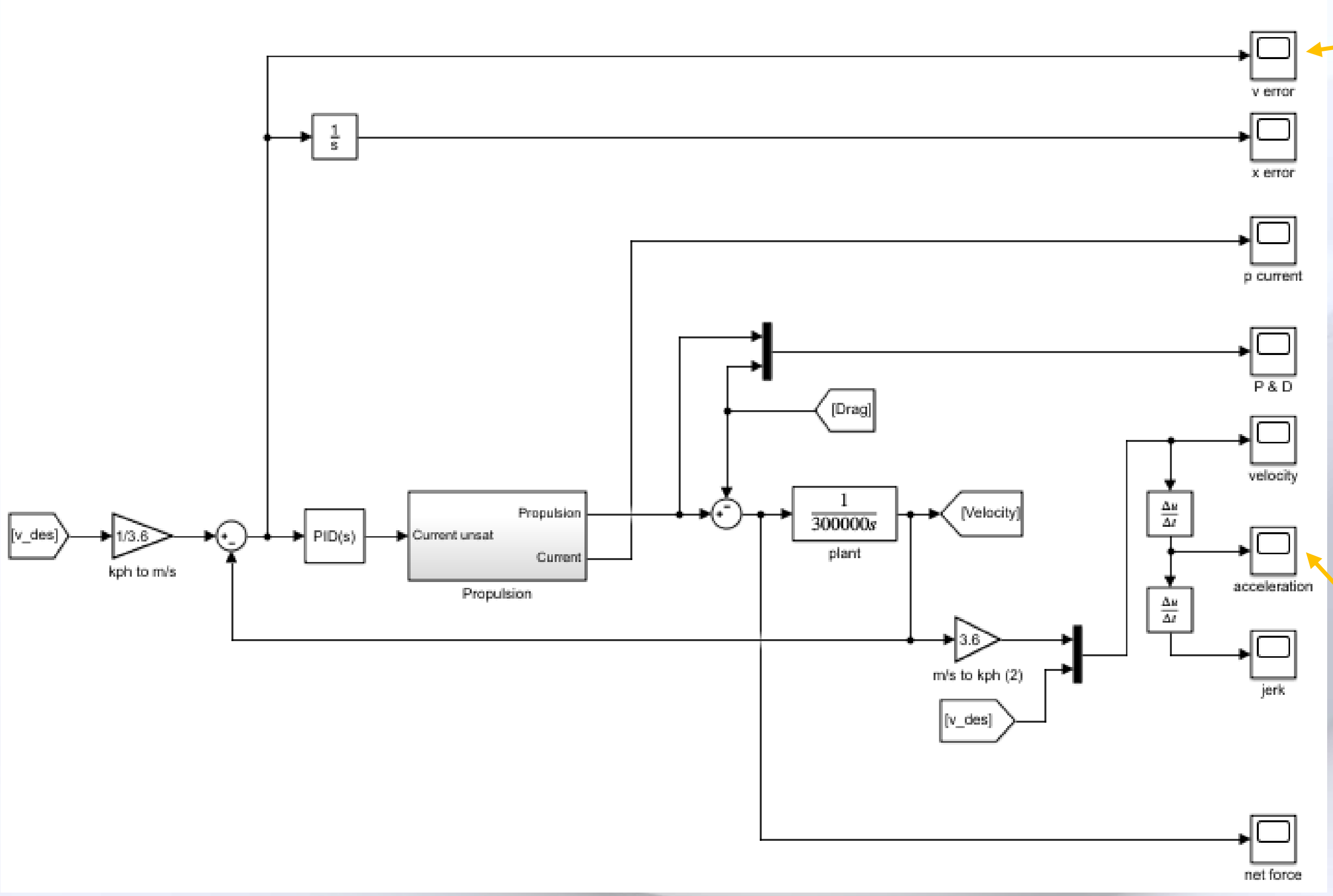


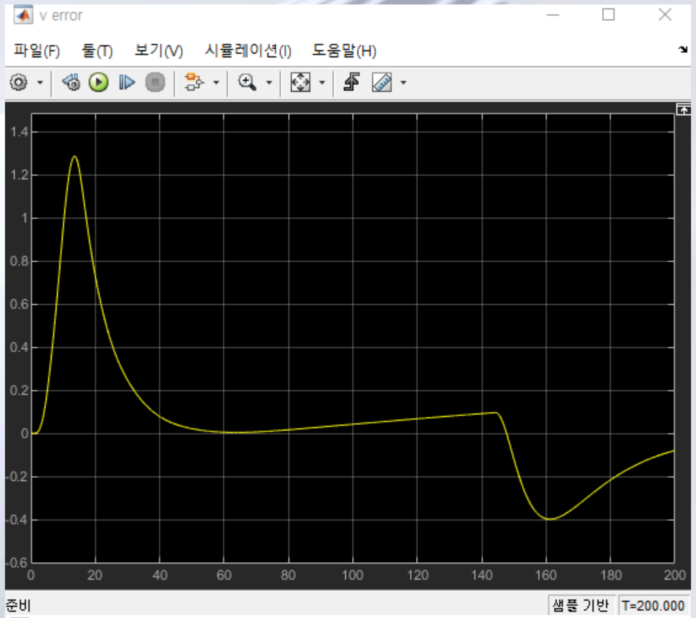
v error
x error
p current
P & D
[Drag]
velocity
acceleration
jerk
net force
[v_des]
1/3.6
kph to m/s
PID(s)
Propulsion
Current unsat
Current
Propulsion
1
300000s
plant
[Velocity]
3.6
m/s to kph (2)
[v_des]

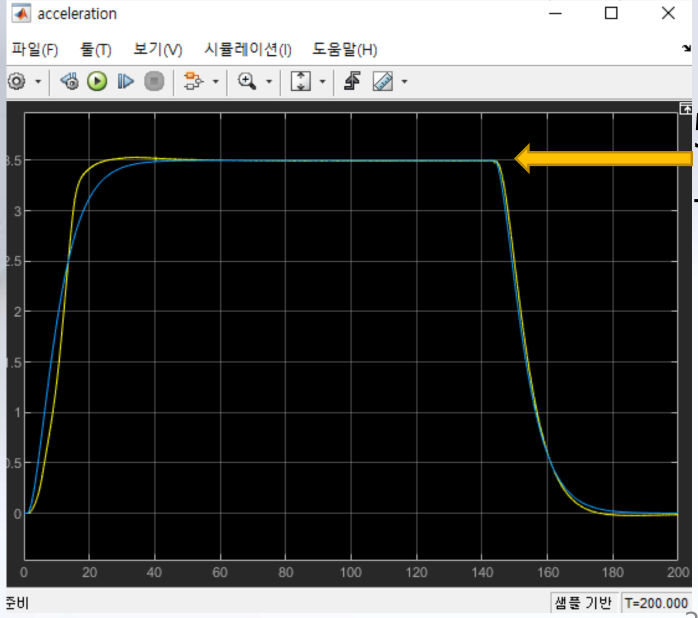


velocity
파일(F) 툴(T) 보기(V) 시뮬레이션(I) 도움말(H)
500
400
300
200
100
0
0 20 40 60 80 100 120 140 160 180 200
준비
샘플 기반
T=200.000

Error







500km/h
도달

Q&A

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