Project Review: Torque Vectoring in Electric vehicles

Course: ME5670 Vehicle Dynamics

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Team:

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Contributions to the project

Team Contribution:

1. Sunrit Samanta MATLAB and Simulink, Report
2. Adireddy Balaji Mathematical modeling, CAD
3. Dwaraknath Reddy Mathematical modeling, CAD
4. Thani Aswanth MATLAB and Simulink, Presentation

Undesirable vehicle steering dynamics:

- Understeer(Ku>0)
- Oversteer (Ku<0)

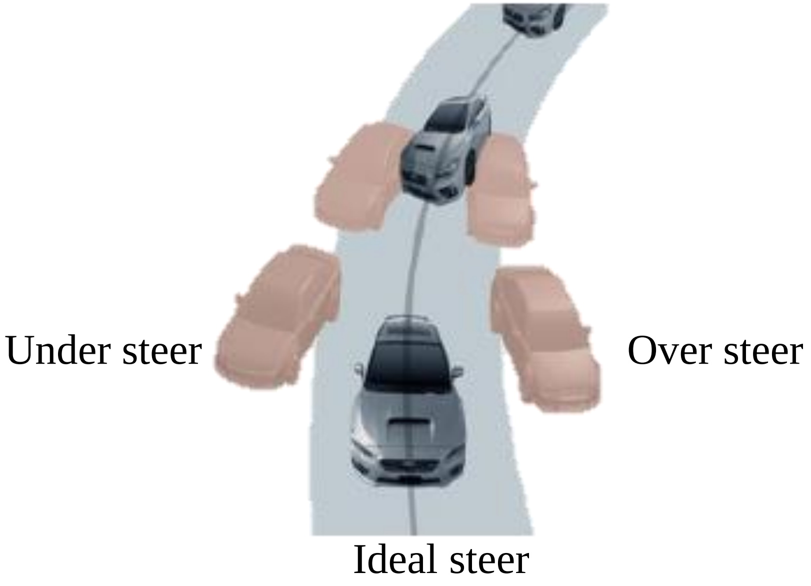
Where Ku = Steer gradient.

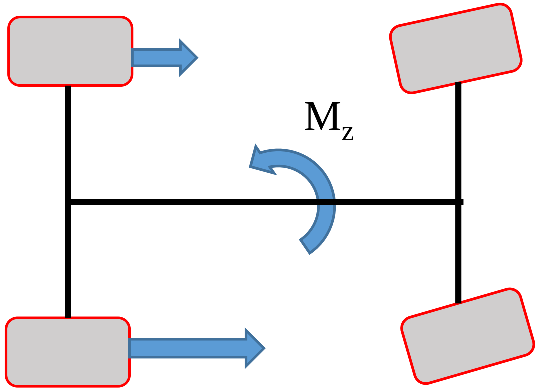
Torque Vectoring:

The vehicle yaw moment is stabilized by the additional yaw moment generated by the difference in the vehicle torque distribution.

Advantages of Torque Vectoring:

- Improved handling.
- Traction when turning.
- Better overall performance in poor road conditions

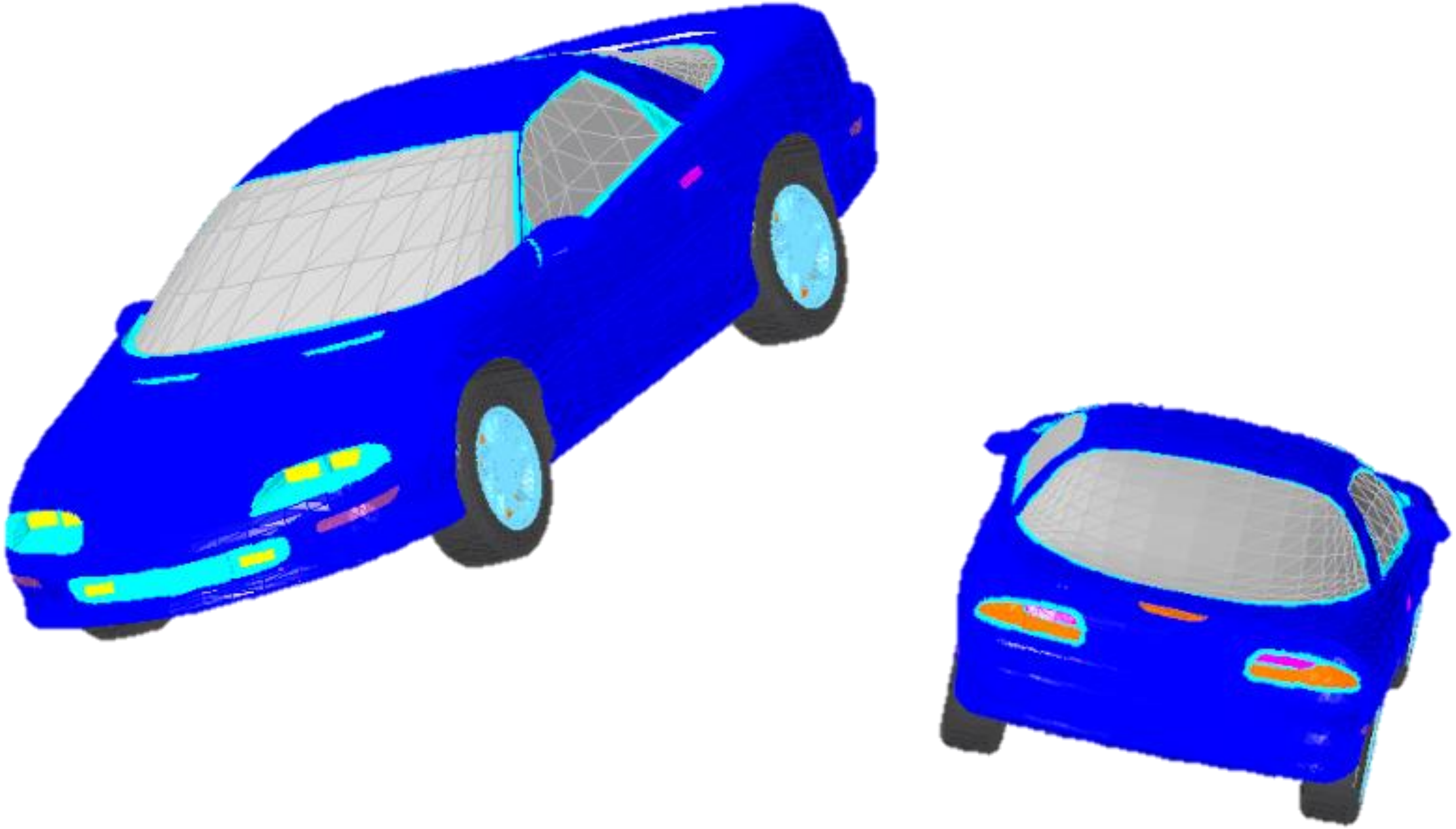




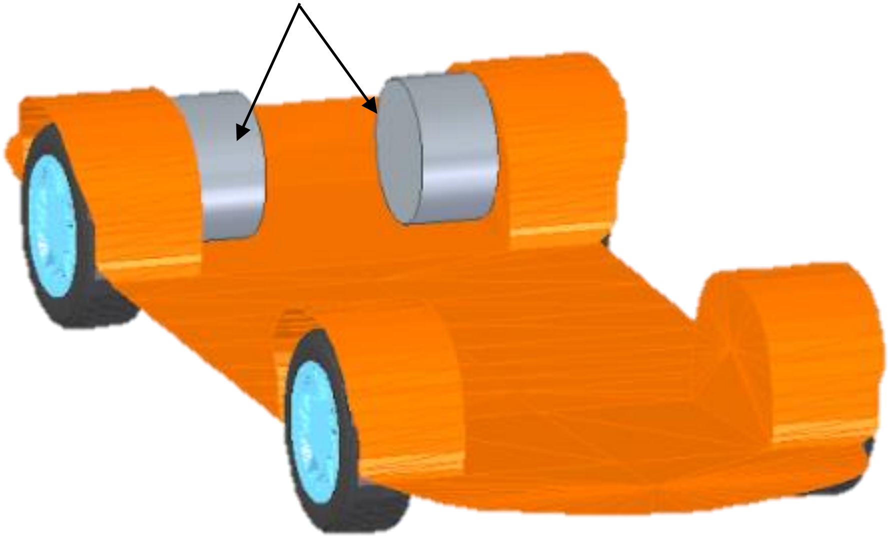
Torque vectoring

CAD Model

Car CAD model



Two individual rear motors



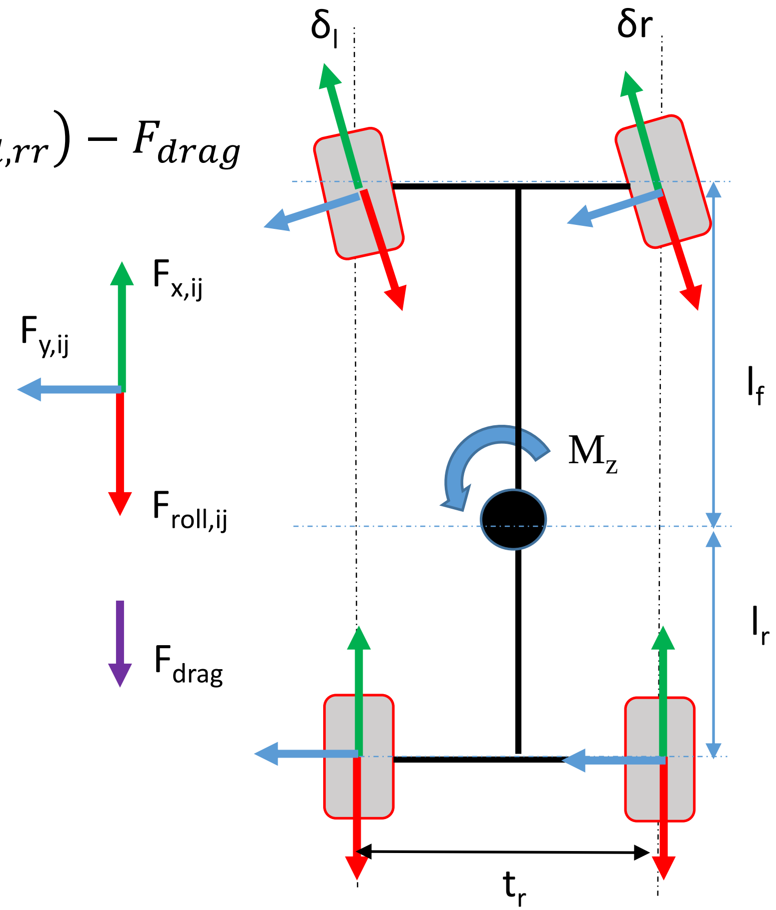
Car Chassis model

Equilibrium conditions:

$$\sum F_x = ma_x = F_{x,fl} + F_{x,fr} + F_{x,rl} + F_{x,rr} - \left(F_{xroll,fl} + F_{xroll,fr} + F_{xroll,rl} + F_{xroll,rr}\right) - F_{drag}$$

$$\sum F_y = ma_y = F_{y,fl} + F_{y,fr} + F_{y,rl} + F_{y,rr} + -\left(F_{yroll,fl} + F_{yroll,fr}\right)$$

$$\sum M_z = I_{zz}\ddot{\psi} = t_r(-F_{x,fl} + F_{x,fr} - F_{x,rl} + F_{x,rr}) + l_f(F_{y,rr} + F_{y,rl}\Big)$$



Linearized Model:

Assumptions:

1. Velocity of the vehicle’s center of gravity is considered constant along the longitude of it’s trajectory.
2. All lifting, rolling and pitching motion will be neglected.
3. The mass of the vehicle is assumed to be at the center of gravity
4. Front and rear tires will be represented as one single tire, one each axle.
5. Aligning torque resulting from the side slip angle will be neglected.
6. The wheel-load distribution between front and rear axles is assumed to be constant.
7. The longitudinal forces on the tires, resulting from the assumption of a constant longitudinal velocity, will be neglected

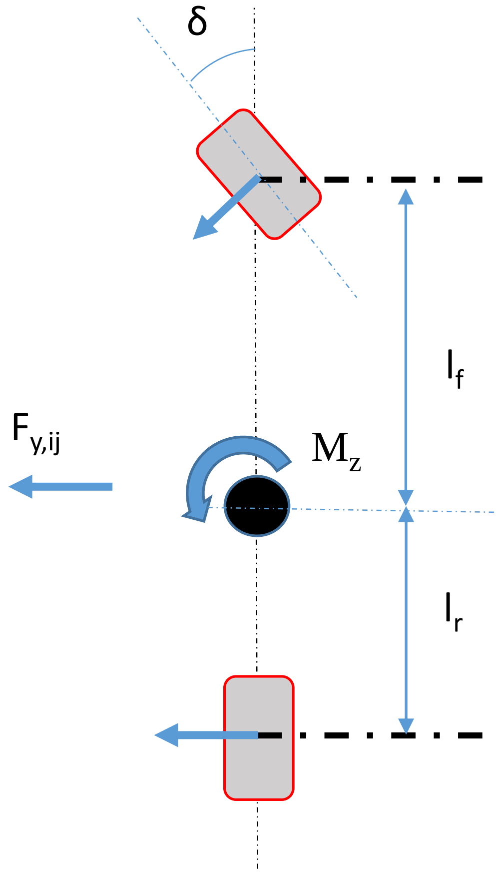
Linearized Model:

Without Torque vectoring:

$$\begin{bmatrix} \dot{v}_y \\ \ddot{\psi} \end{bmatrix} = \begin{bmatrix} -\frac{C_{y,f} + C_{y,r}}{m v_{x0}} & \frac{-l_f C_{y,f} + l_r C_{y,r}}{m v_{x0}} - v_{x0} \\ \frac{-l_f C_{y,f} + l_r C_{y,r}}{I_{zz} v_{x0}} & \frac{l_f^2 C_{y,f} + l_r^2 C_{y,r}}{I_{zz} v_{x0}} \end{bmatrix} \begin{bmatrix} v_y \\ \dot{\psi} \end{bmatrix} + \begin{bmatrix} \frac{C_{y,f}}{m v_{x0}} \\ \frac{l_f C_{y,f}}{I_{zz}} \end{bmatrix} \delta$$

With Torque vectoring:

$$\begin{bmatrix} \dot{v}_y \\ \ddot{\psi} \end{bmatrix} = \begin{bmatrix} -\frac{C_{y,f} + C_{y,r}}{m v_{x0}} & \frac{-l_f C_{y,f} + l_r C_{y,r}}{m v_{x0}} - v_{x0} \\ \frac{-l_f C_{y,f} + l_r C_{y,r}}{I_{zz} v_{x0}} & \frac{l_f^2 C_{y,f} + l_r^2 C_{y,r}}{I_{zz} v_{x0}} \end{bmatrix} \begin{bmatrix} v_y \\ \dot{\psi} \end{bmatrix} + \begin{bmatrix} \frac{C_{y,f}}{m v_{x0}} \\ \frac{l_f C_{y,f}}{I_{zz}} \end{bmatrix} \delta + \begin{bmatrix} 0 \\ \frac{1}{0.05 * I_{zz}} \end{bmatrix} \Delta T$$



Mathematical Model: Desired yaw rate

Under steer gradient:

$$K_u = \frac{l_r m}{C_{y,f}(l_r+l_f)} - \frac{l_f m}{C_{y,r}(l_r+l_f)}$$

Turning radius:

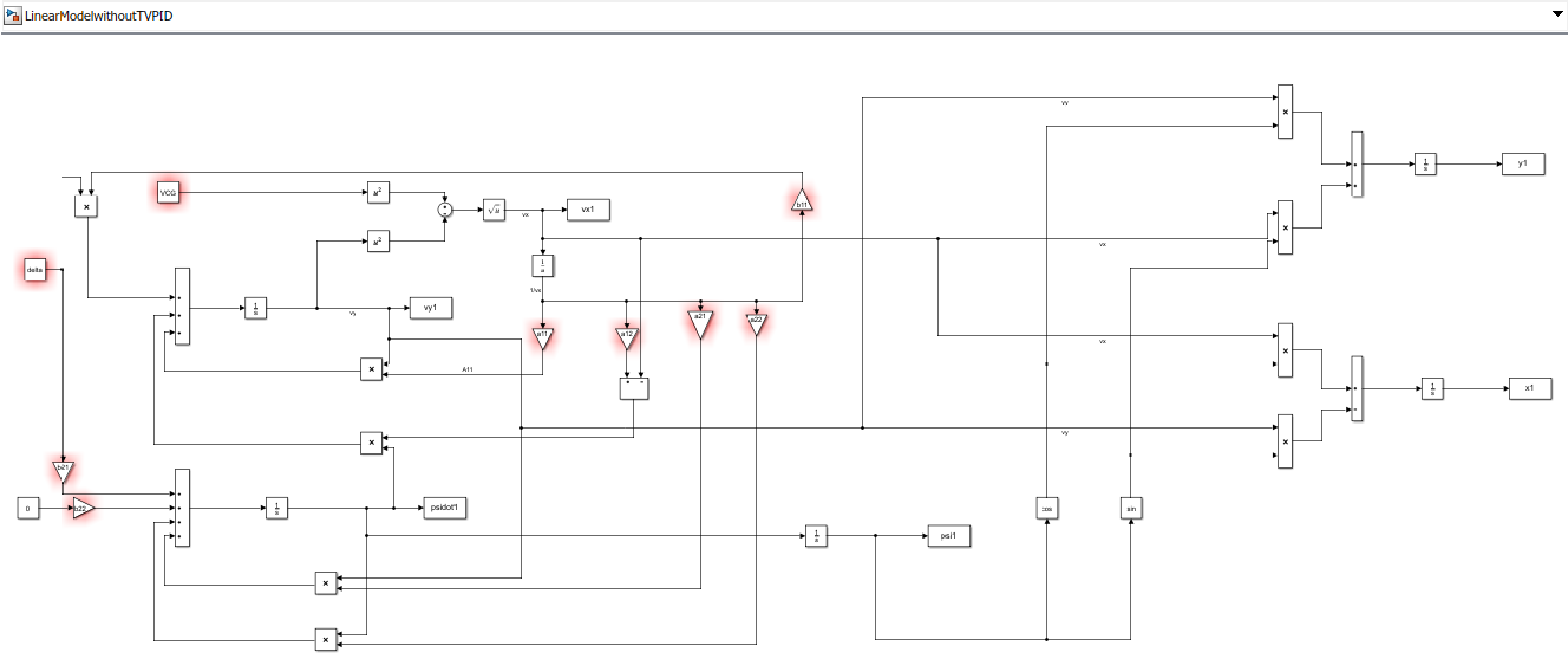
$$\frac{1}{R} = \frac{\delta}{(l_r + l_f) + K_u VCG^2}$$

Desired yaw rate:

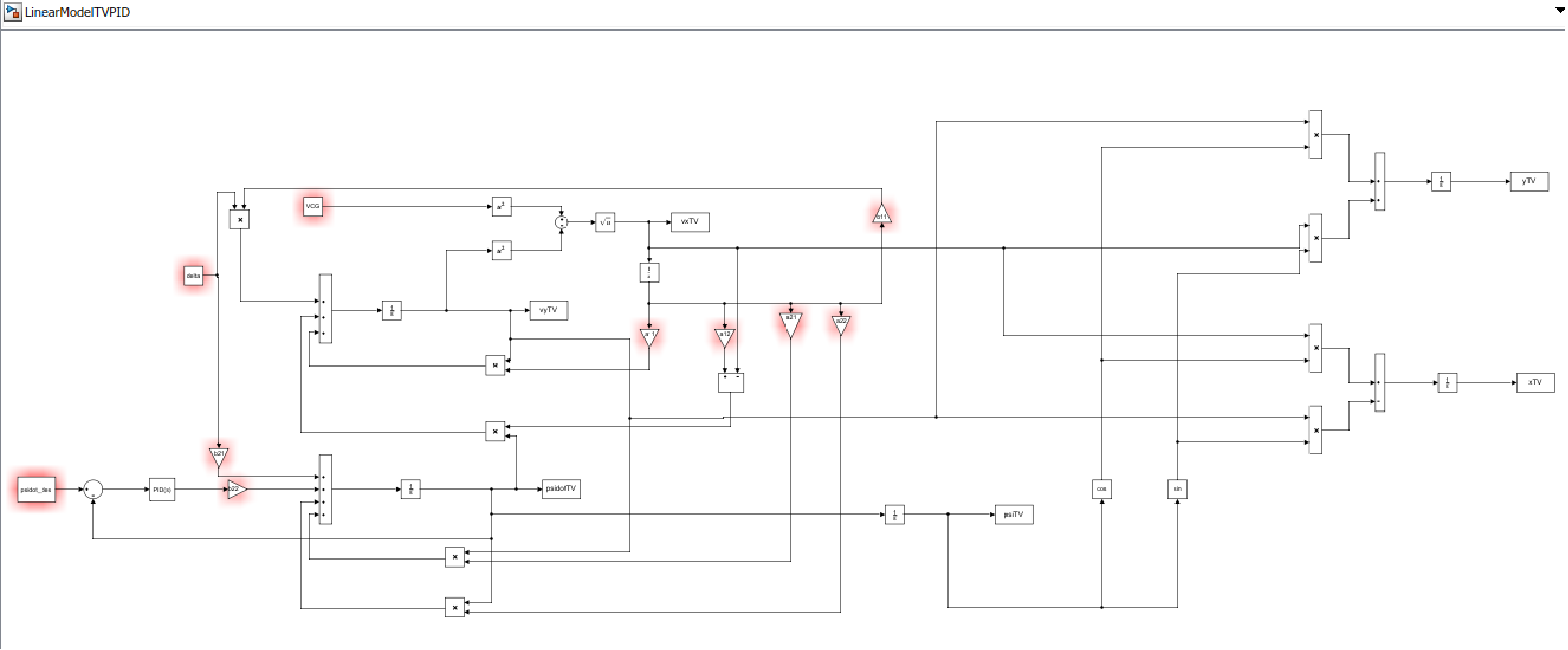
$$\dot{\psi}_{desired} = \frac{VCG}{R}$$

Term	Symbol	Value
Yaw rate	---	$\dot{\psi}$
Longitudinal velocity	-----	v_{xo}
Cornering Stiffness at Rear wheel	745	$C_{y,r}$
Cornering Stiffness at Front wheel	546	$C_{y,f}$
Inertia Moment	120	I_{zz}
Mass	356	m
Front wheel base	0.873	l_f
Rear Wheel base	0.717	l_r
Steering angle	70 degrees	δ
Torque diff between rear wheels	----	ΔT
Lateral Velocity	----	v_y
Vehicle velocity	----	VCG

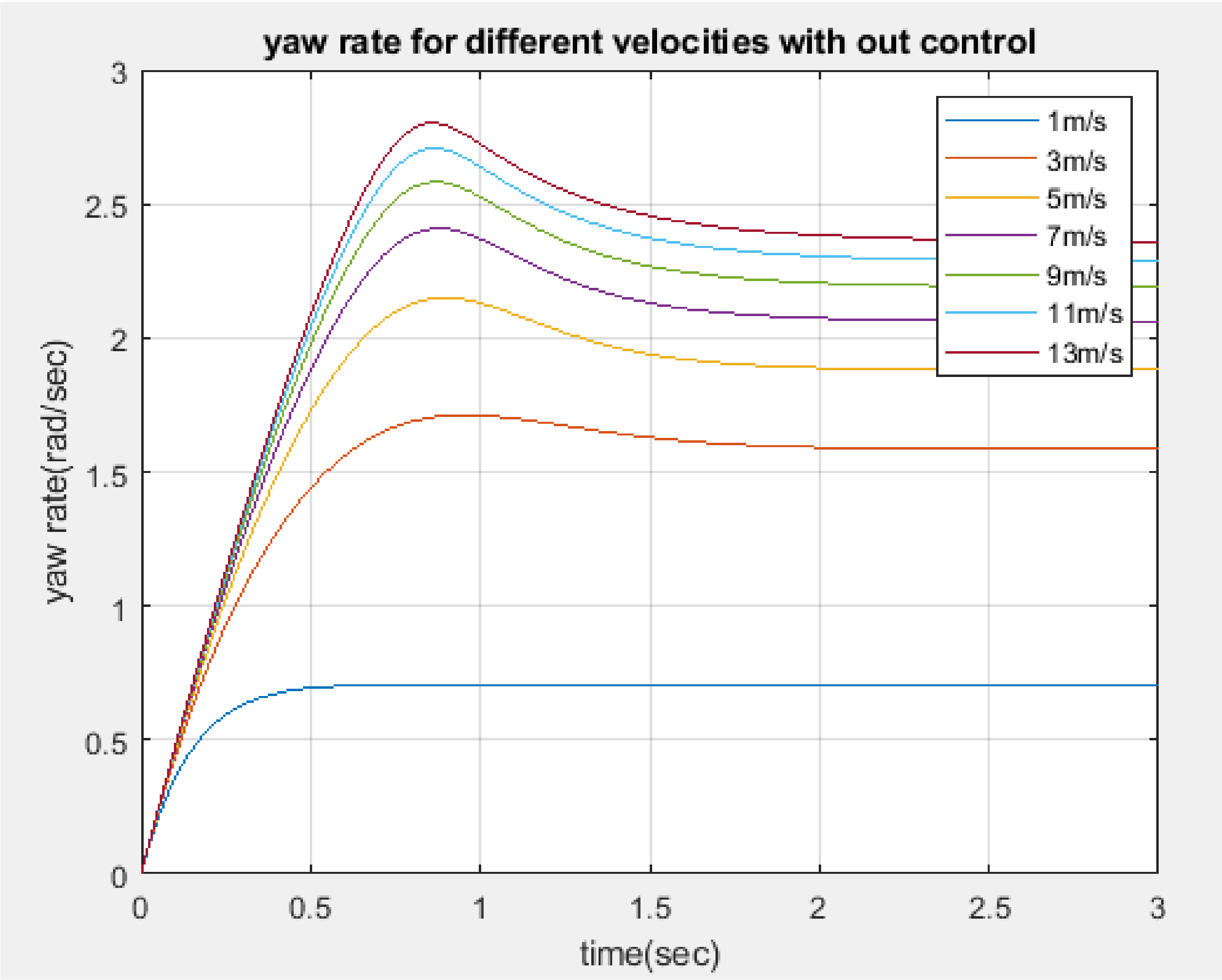
Simulink Model: Without Torque Vectoring

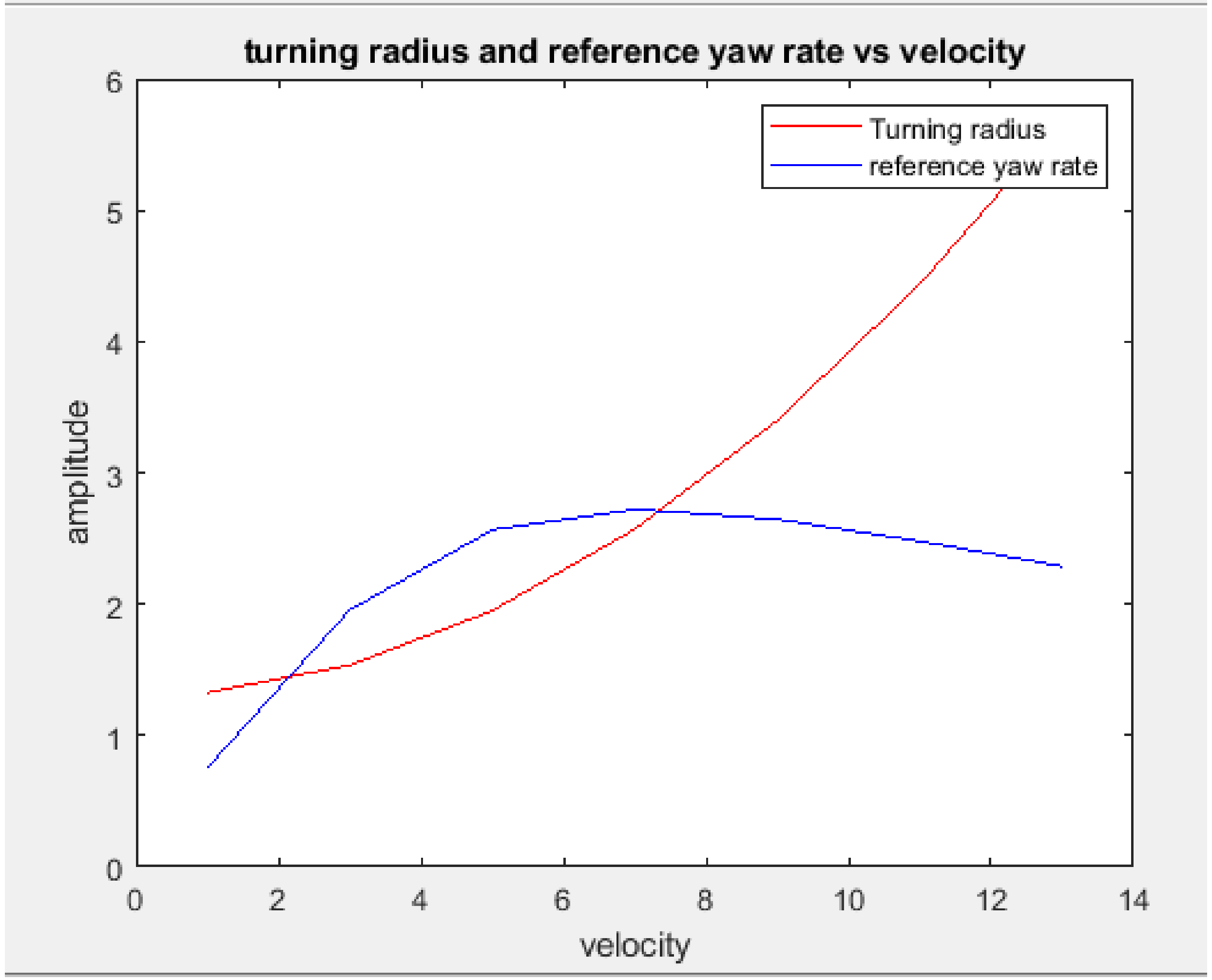


Simulink Model: With Torque Vectoring

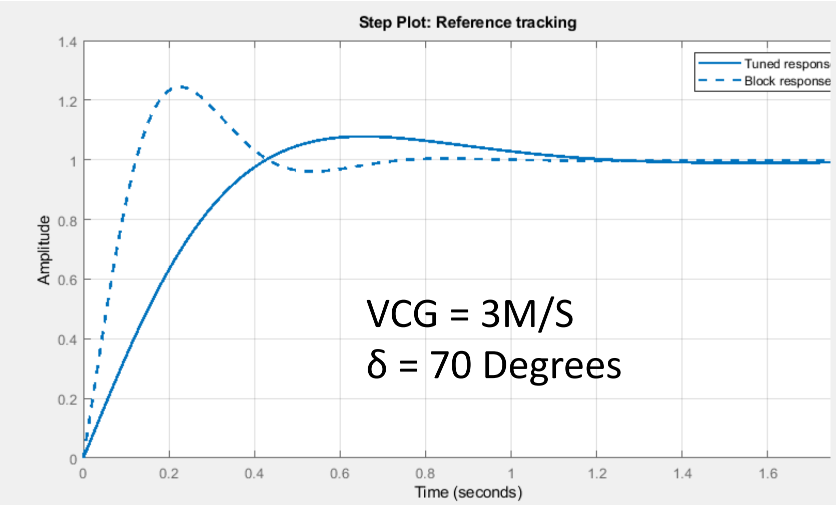


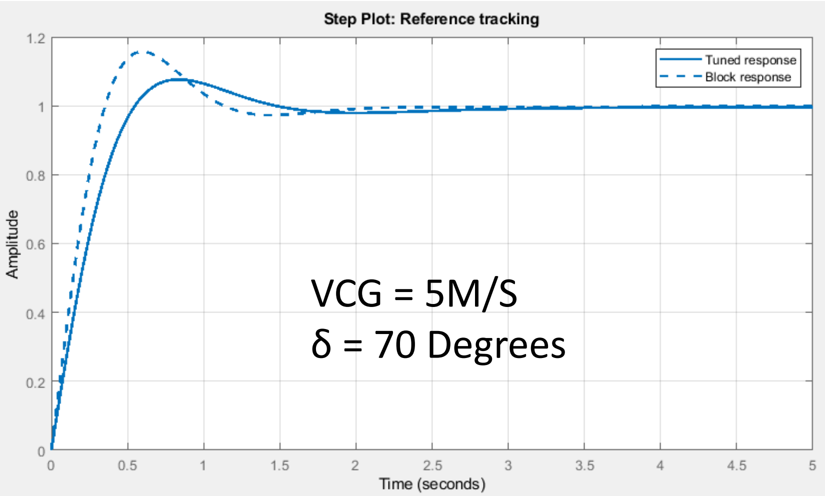
Results:

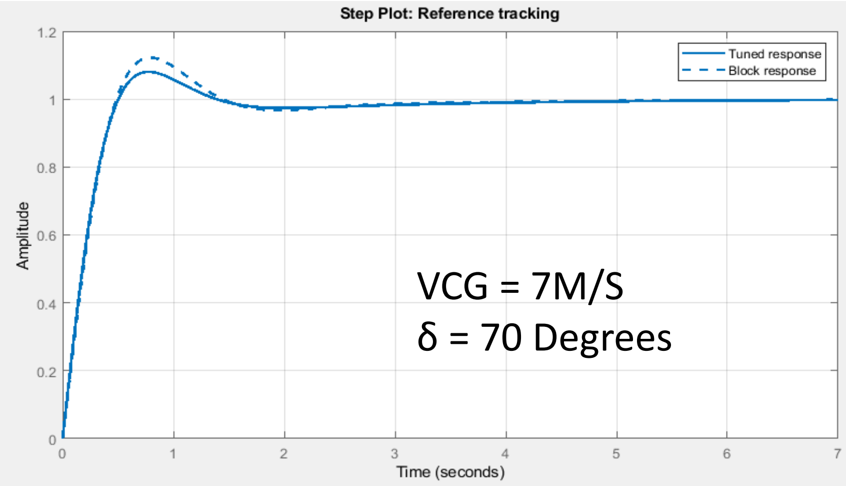

yaw rate for different velocities with out control
yaw rate(rad/sec)
time(sec)
0
0.5
1
1.5
2
2.5
3
1m/s
3m/s
5m/s
7m/s
9m/s
11m/s
13m/s

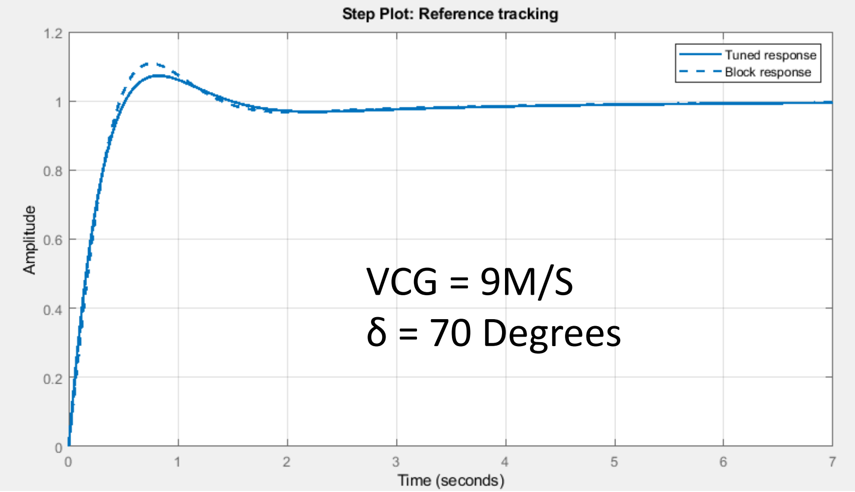

turning radius and reference yaw rate vs velocity
amplitude
velocity
0
1
2
3
4
5
6
8
10
12
14
Turning radius
reference yaw rate

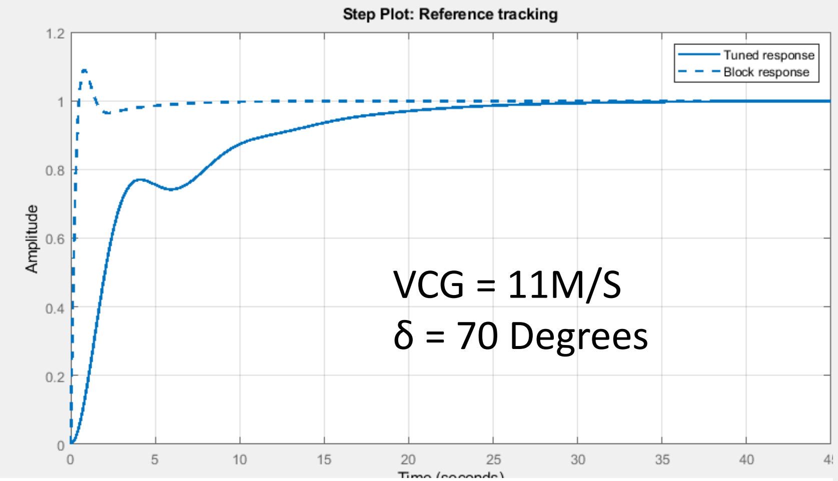
Results: Tuning for optimal PID Gains

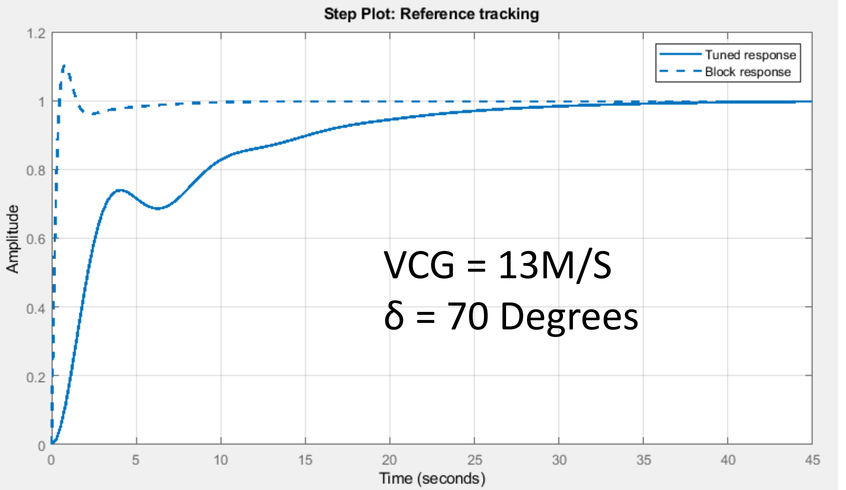




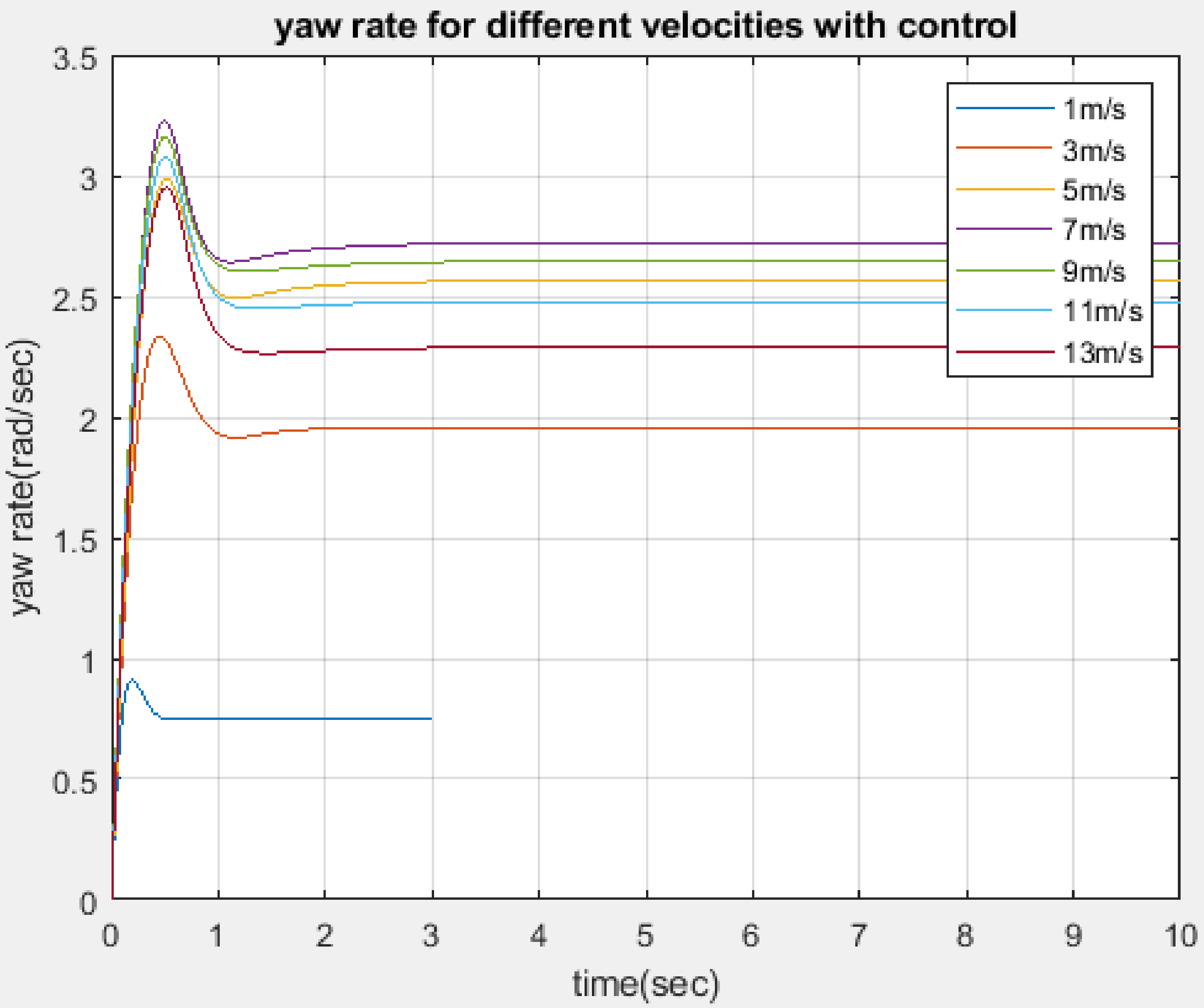


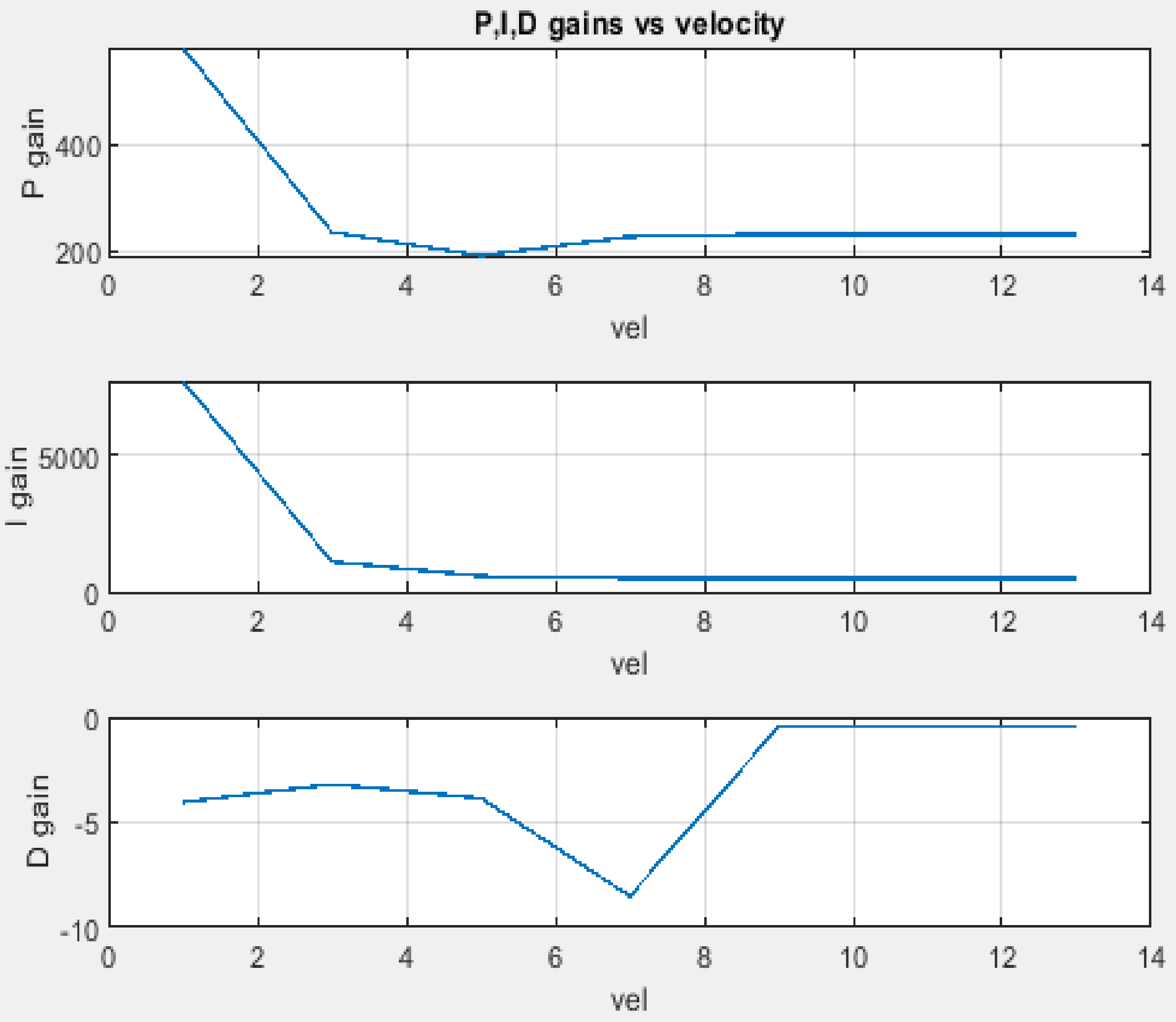




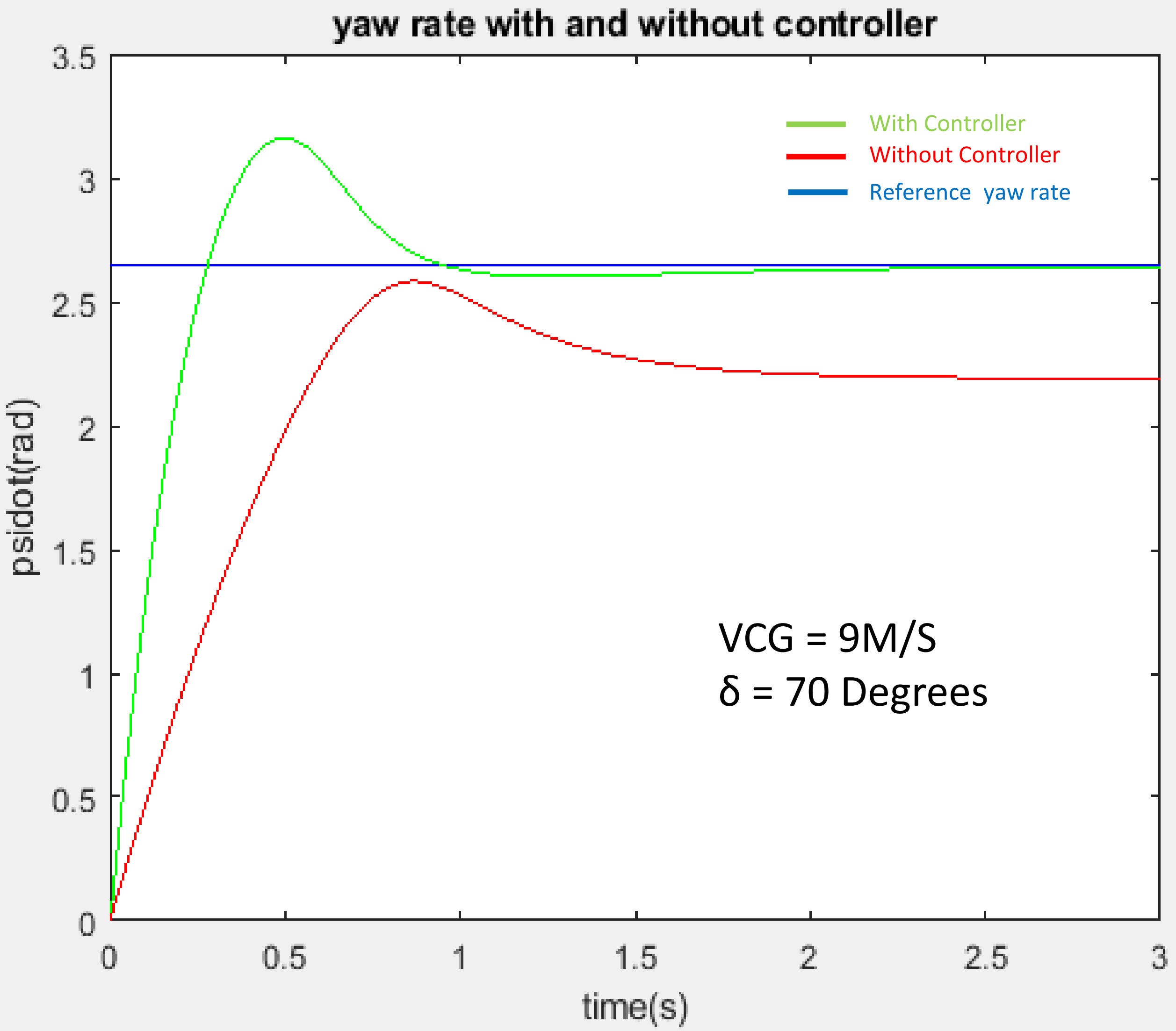


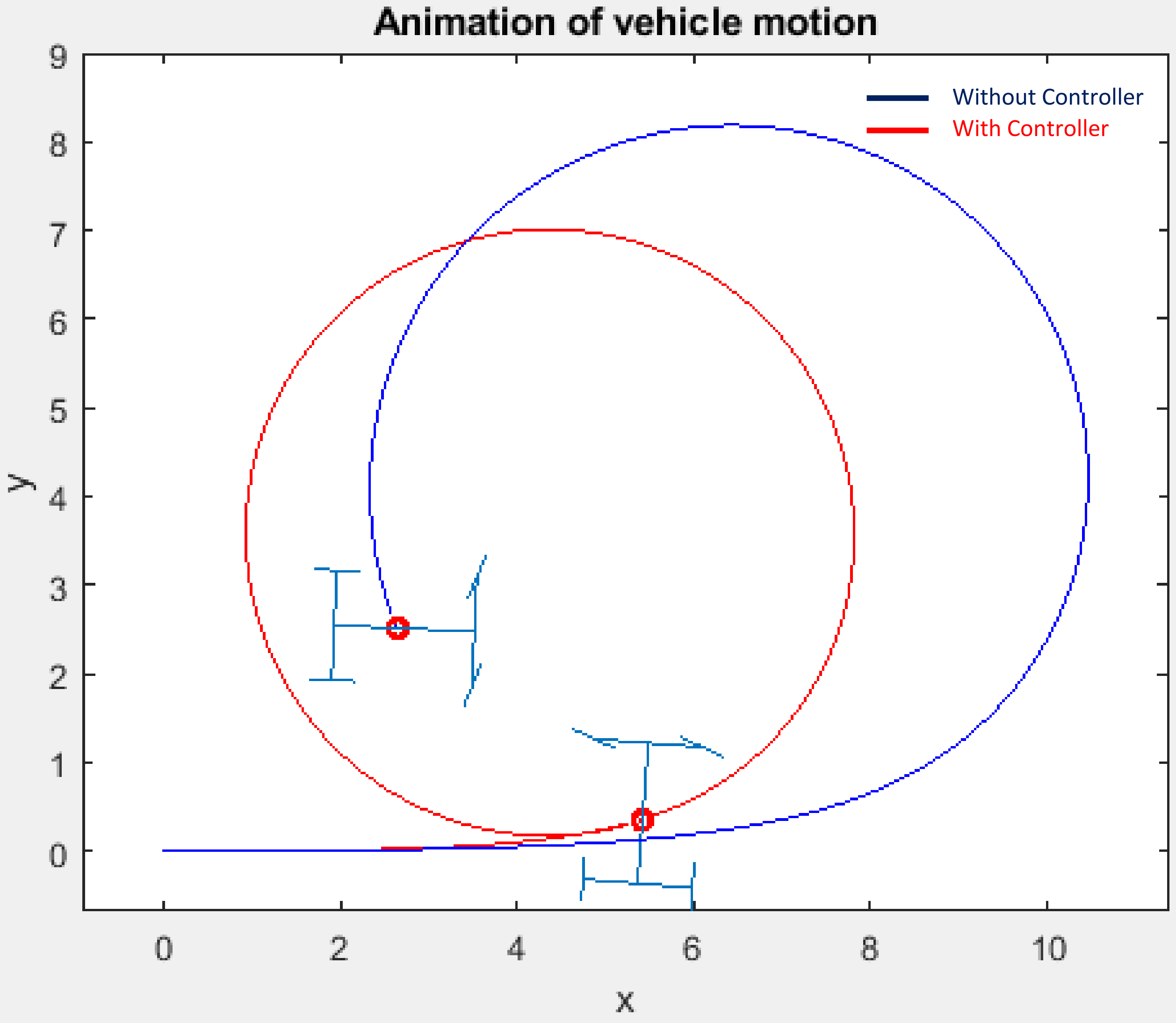
Results:


yaw rate for different velocities with control
yaw rate(rad/sec)
time(sec)
1m/s
3m/s
5m/s
7m/s
9m/s
11m/s
13m/s
0
0.5
1
1.5
2
2.5
3
3.5
0
1
2
3
4
5
6
7
8
9
10


P,I,D gains vs velocity
P gain
200
400
I gain
0
5000
D gain
0
-5
-10
vel
0
2
4
6
8
10
12
14

Results: Comparision





References:

1. Torque Vectoring for a Formula Student Prototype , João Pedro Marques Antunes
2. Independent control of all-wheel-drive torque distribution, Russell P. Osborn a & Taehyun Shim b
3. Active torque vectoring systems for electric drive vehicles, Martin Mondek