Control System for Cornering in Heavy Vehicles

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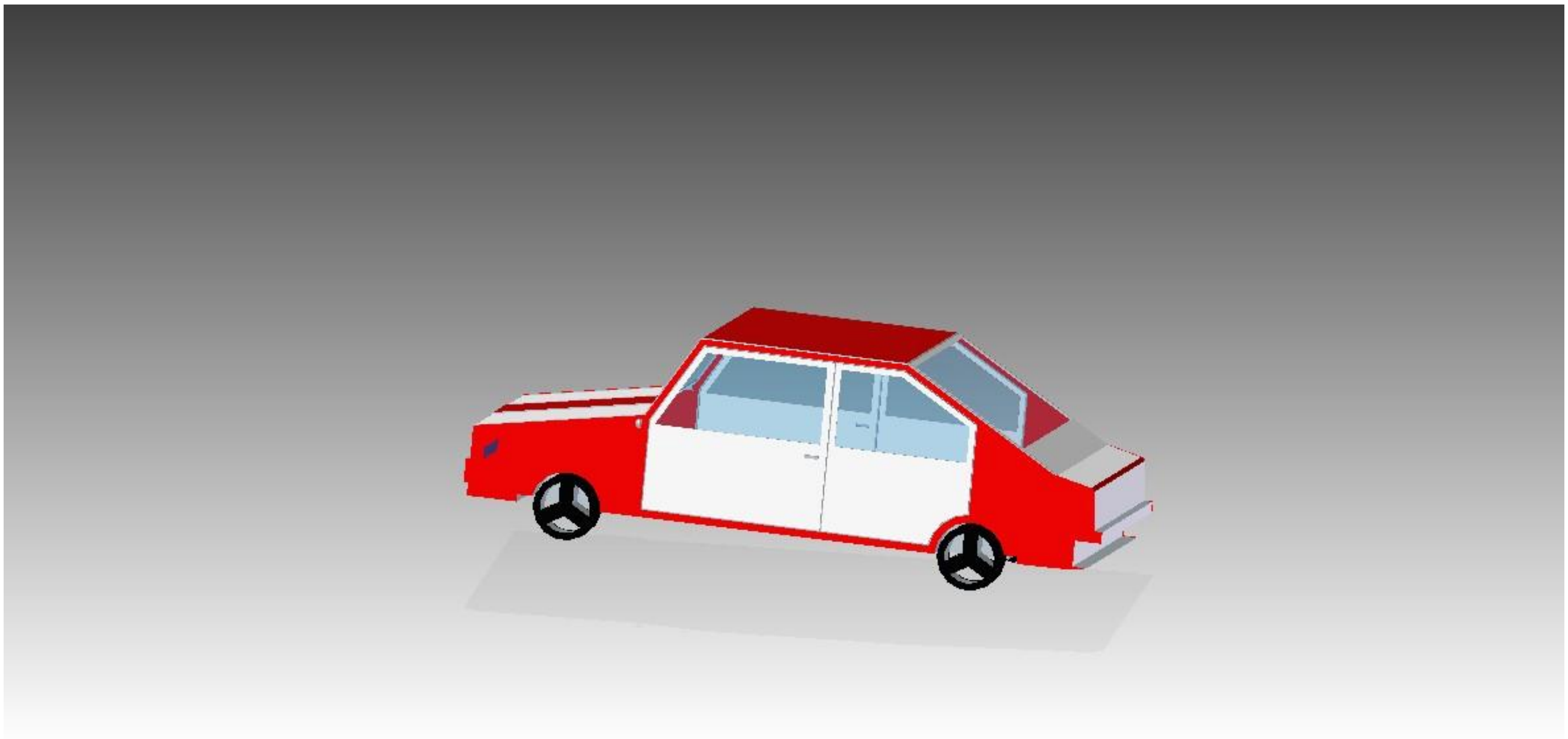
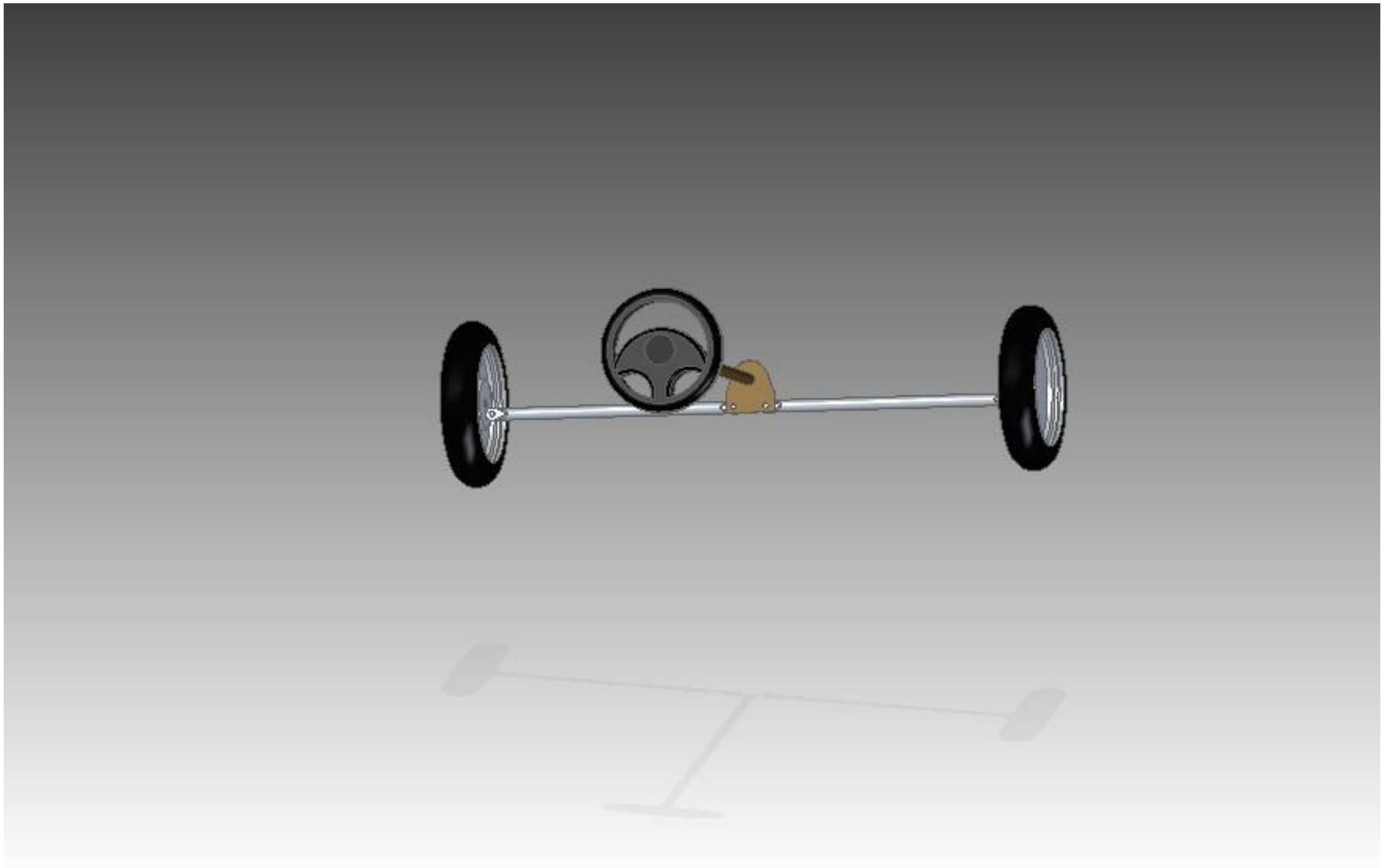
CAD model

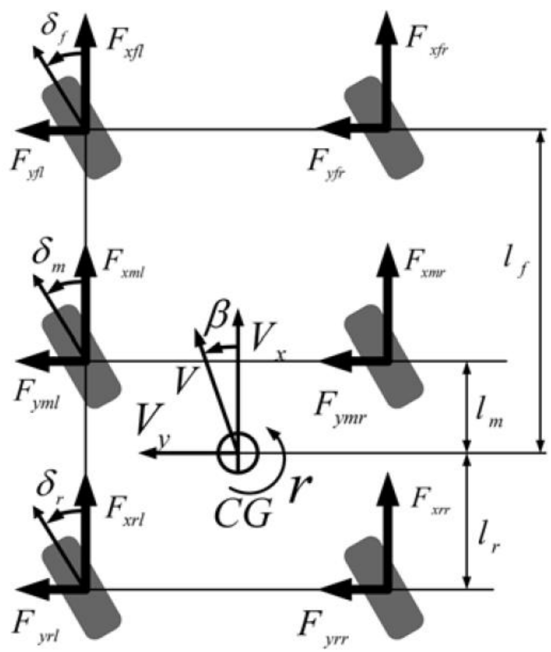


CAD model



- An independent 6 wheel drive mechanism is adopted in a special purposed, military armored vehicle to enhance its steering performance and its drive capability as an off-road.
- In order for a six-wheeled vehicle to achieve the best maneuverability during cornering, the middle and rear wheel steering angles need to be controlled according to the steering angle of the front wheels and velocity of the six-wheeled vehicle.

- As a full vehicle model is complex to process (DOF 18) , we are using a 2 DOF bicycle model**.**



- It is assumed that the vehicle is traveling at a constant forward velocity, V_x . Assuming equal lateral tire forces on the left and right wheel,the dynamics equation can be written as

$$mV_x(\dot{\beta}+\gamma)=2F_{yf}+2F_{ym}+2F_{yr}$$

$$I_z\dot{r}=2l_fF_{yf}+2l_mF_{ym}-2l_rF_{yr}$$

Where m is the mass of vehicle
β is the side slip angle
I_z is the moment of inertia
r is the yaw rate
F_{yf}, F_{ym}, F_{yr} are the front, middle, and rear tire forces, respectively
l_f l_m, l_r are the distances from the center of gravity (CG) to the tires

- From the above equations , we get

$$F_{yf} = C_f\left(\delta_f - \frac{\beta V_x - l_f r}{V_x}\right)$$

$$F_{ym} = C_m\left(\delta_m - \frac{\beta V_x + l_m r}{V_x}\right)$$

$$F_{yr} = C_r\left(\delta_r - \frac{\beta V_x + l_r r}{V_x}\right)$$

Where C_f, C_m, C_r is the cornering stiffness of tires
G_f, G_m, G_r is the steering angles of tires.

- Defining the state vector x as $x=[\beta\ r]^T$

  the control input u as $u=[\delta_f\ \delta_m\ \delta_r]^T$

  the following state space representation is obtained.

$$\dot{x}=Ax+Bu$$

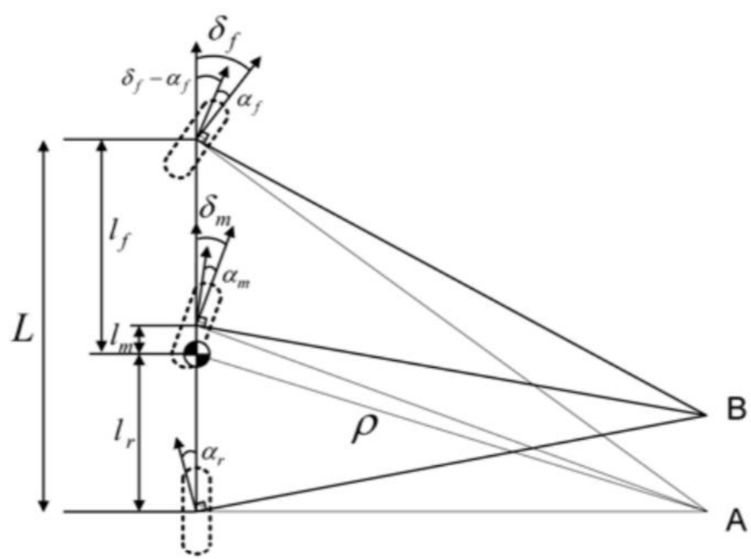
Where A is

$$A=\begin{bmatrix} \dfrac{-2(C_f+C_m+C_r)}{mv_x} & \dfrac{-2(l_f C_f+l_m C_m-l_r C_r)}{mv_x^2}-1 \\ \dfrac{-2(l_f C_f+l_m C_m-l_r C_r)}{I_z} & \dfrac{-2(l_f^2 C_f+l_m^2 C_m-l_r^2 C_r)}{I_z v_x} \end{bmatrix},$$

and B is

$$B=\begin{bmatrix} \dfrac{2C_f}{mv_x} & \dfrac{2C_m}{mv_x} & \dfrac{2C_r}{mv_x} \\ \dfrac{2l_f C_f}{I_z} & \dfrac{2l_m C_m}{I_z} & \dfrac{2l_r C_r}{I_z} \end{bmatrix}$$

- In low-speed turning, the tire need not develop a lateral force. Thus they roll with no slip angle. For proper geometry in the turn (assuming small angles), the front wheel steering angle is defined as the Ackerman angle:



$$\delta_f = \frac{L}{\rho}$$

- The relationship between the front wheel steering angle and the middle wheel steering angle is defined as follows:

$$\delta_m = \frac{l_m + l_r}{\rho} = \frac{L - l_f + l_m}{\rho}$$

$$\delta_m = \delta_f - \frac{(l_f - l_m)}{\rho} \Leftarrow r = \frac{V_x}{\rho}, \ \frac{1}{\rho} = \frac{r}{V_x}$$

$$= \delta_f - \left(\frac{r}{V_x}\right)(l_f - l_m)$$

$$= \delta_f \left(\frac{l_m + l_r}{L}\right)$$

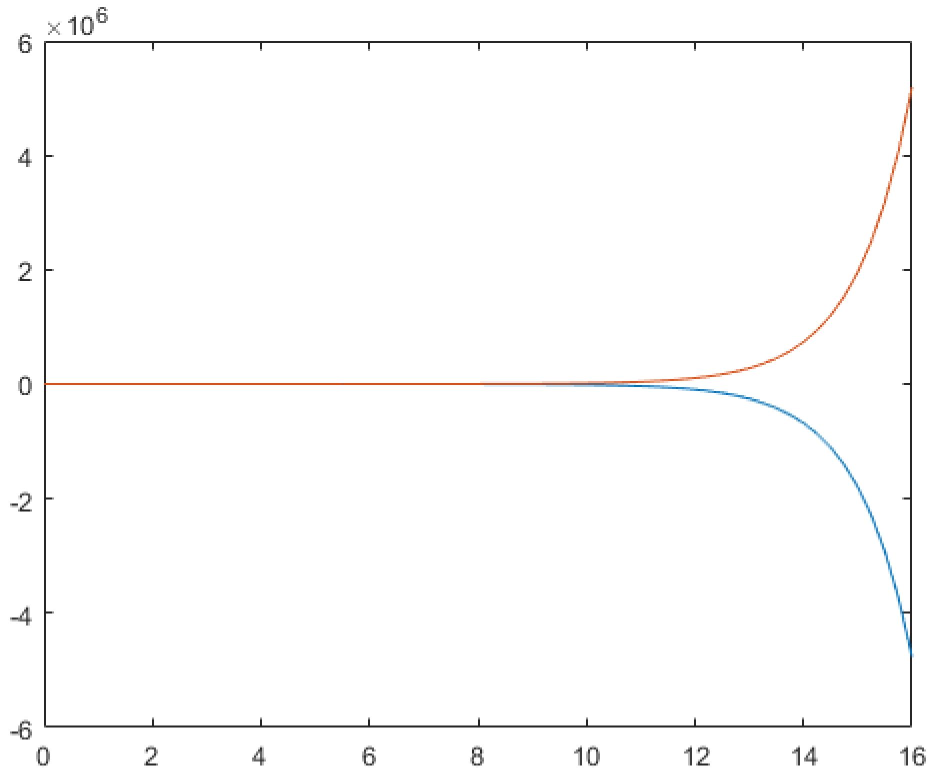
- When $\delta_r = 0$,

$$\begin{bmatrix}\dot{\beta}\\ \dot{r}\end{bmatrix} = \begin{bmatrix}a_{11} & a_{12}\\ a_{21} & a_{22}\end{bmatrix}\begin{bmatrix}\beta\\ r\end{bmatrix} + \begin{bmatrix}b_{11}\\ b_{21}\end{bmatrix}\delta_f + \begin{bmatrix}b_{12}\\ b_{22}\end{bmatrix}\delta_m$$

$$= \begin{bmatrix}a_{11} & a_{12}\\ a_{21} & a_{22}\end{bmatrix}\begin{bmatrix}\beta\\ r\end{bmatrix} + \begin{bmatrix}b_{11}\\ b_{21}\end{bmatrix}\delta_f + \begin{bmatrix}b_{12}\\ b_{22}\end{bmatrix}\delta_f\left(\frac{l_m + l_r}{L}\right)$$

$$= \begin{bmatrix}a_{11} & a_{12}\\ a_{21} & a_{22}\end{bmatrix}\begin{bmatrix}\beta\\ r\end{bmatrix} + \begin{bmatrix}b_{11} + b_{12}\left(\frac{l_m + l_r}{L}\right)\\ b_{21} + b_{22}\left(\frac{l_m + l_r}{L}\right)\end{bmatrix}\delta_f$$

Graph



Conclusion

- We get such a graph as we took del(r) as zero which is not the case especially at high speeds.
- With slow speeds and shorter radius the cornering takes which place is more stable.

Reference

- Lateral Control of Commercial Heavy Vehicles

  by Chieh Chen & Masayoshi Tomizuka.
- How well a single-track linear model captures the lateral dynamics of long combination vehicles by M. M. Islam, N. Fröjd, S. Kharrazi & B. Jacobson

THANK YOU