ME41100
Vehicle Dynamics-A

Application of Anti-Roll Bar to Enhance Vehicle Performance

Submitted by Group 10:

- **Blauw M. - 4195809**
- **Chatrath K. – 4739205**
- **Chowdhri N. – 4744055**
- **Damian M. – 4749405**
- **Vitiello P. - 4719557**

Course Instructor:
Barys Shyrokau

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Problem Statement

- **National Highway Traffic Safety Administration (NHTSA - 2011),**
  - **46.4% of the fatal traffic accidents**

- **Vehicle body roll affects,**
  - **Road holding**
  - **Ride handling**
  - **Ride comfort**

- **Active suspension system is an expensive technology**

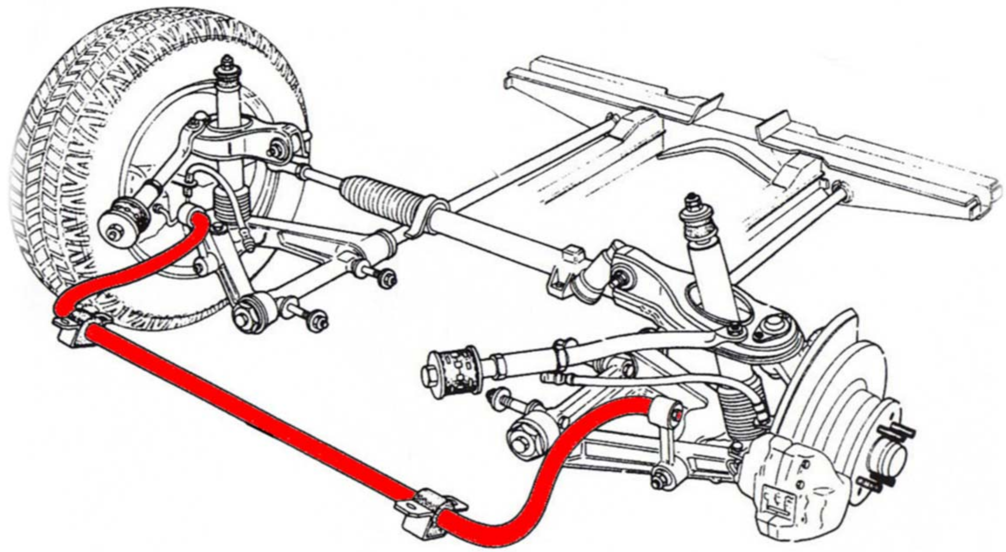
How to effectively and cost efficiently reduce the vehicle's body roll, enhancing its performances?

[1] "Traffic Safety Facts - 2011 Data: Overview - 811753," Apr 2018, [Online; accessed 5. Apr. 2018]. [Online]. Available: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/811753

Anti-Roll Bar (ARB)

- An anti-roll bar is intended to force each side of the vehicle to lower, or rise, to similar heights:
  - to reduce the sideways tilting (roll) of the vehicle
  - counteracting the inertial forces during cornering maneuvers

- The bar's torsional stiffness (resistance to twist) determines its ability to reduce body roll, and is named as "Roll Stiffness"



- Properties (Steel):
  - Rolling Stiffness: 408.56 Nm/deg
  - Mass of the Bar: 1.86 Kg
  - Outer Diameter: 21.8 mm
  - Inner diameter: 16 mm

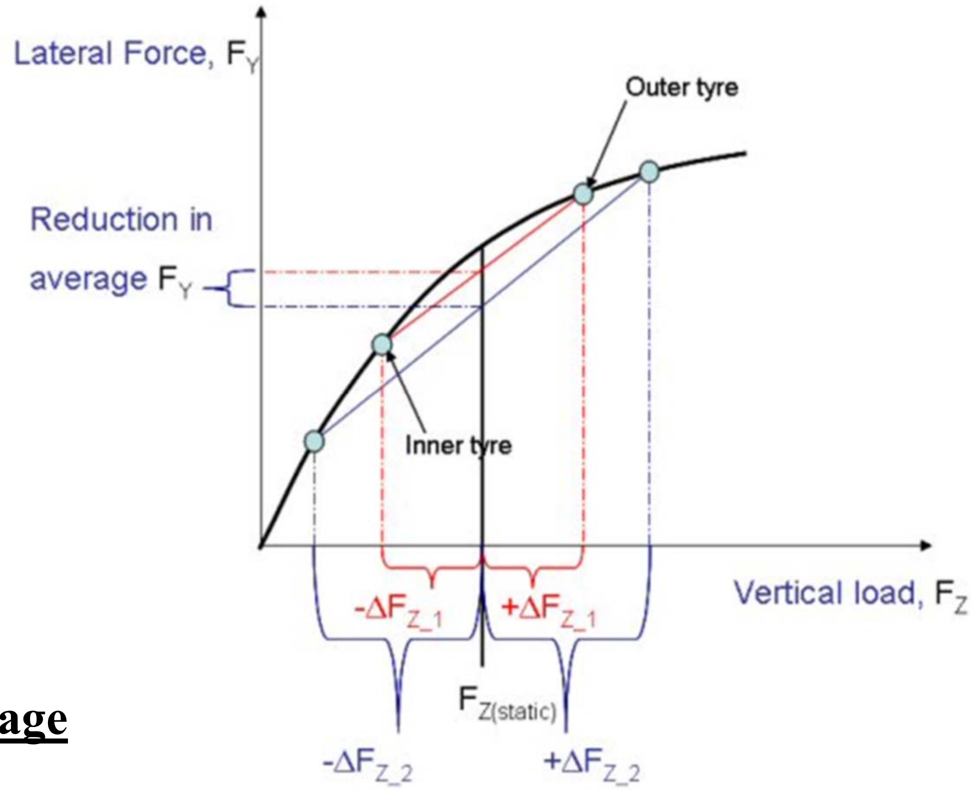
[2] Design, Analysis and Optimization of Anti-Roll Bar [2014]

Anti-Roll Bar (ARB)

- The amount of lateral load transfer that occurs between two wheels of an axle has a significant influence on vehicle's lateral or handling dynamics.

- During a maneuver, <u>the normal force on left and right wheels are not equal in magnitude.</u>

- This behavior <u>results in a net decrease in average lateral force of the axle during corners</u> and is proportional to the amount of load transfer.



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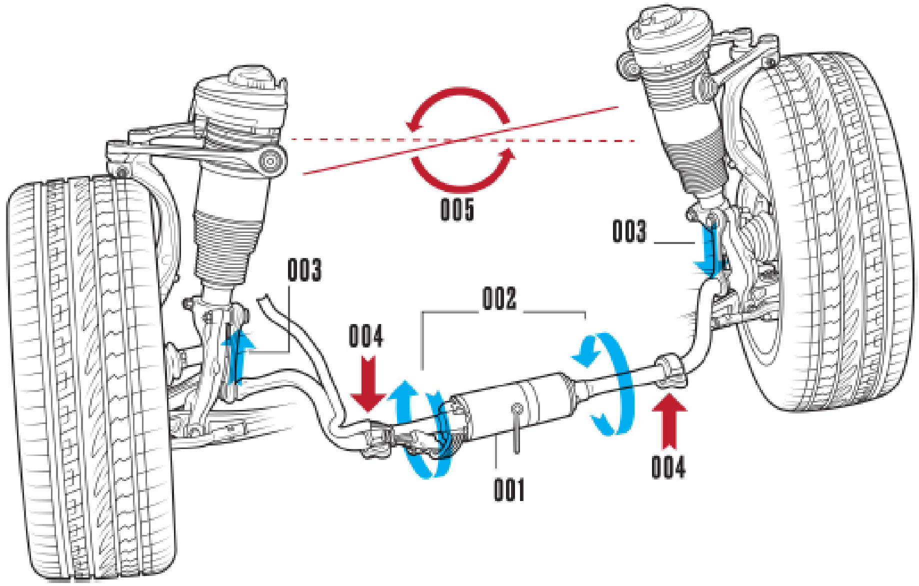
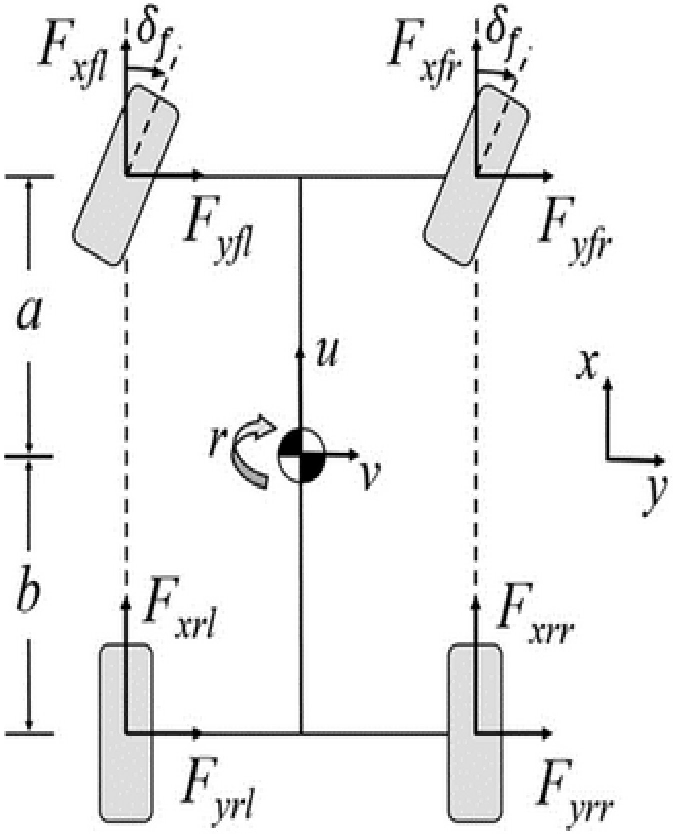
Active Anti-Roll Bar (A-ARB)

- The design drawback of an ARB is that it couples the two wheels of an axle.
- If one of the wheels would hit an obstacle such as a pothole then this will induce torsion of the ARB and hence both wheels will be effected.
  - In such a situation, this is often referred to as the copying effect.
- This gives a higher negative impact on ride comfort.
- To reduce this trade-off active ARBs, with variable stiffness, are considered.
- Double-lead compensator



Vehicle Model

- The vehicle model considered is a 8 DOFs model



$$
\begin{aligned}
m(\dot{u}-vr)-m_s\dot{r}\dot{\phi}h\cos(\phi) &= \Sigma F_x, \\
F_{x,fl}+F_{x,fr}+F_{x,rl}+F_{x,rr} &= \Sigma F_x, \\
m(\dot{v}-ur)-m_s\ddot{\phi}h\cos(\phi) &= \Sigma F_y, \\
F_{y,fl}+F_{y,fr}+F_{y,rl}+F_{y,rr} &= \Sigma F_y, \\
I_{zz}\dot{r}-I_{xz}\ddot{\phi}+m_s a_x h_s\sin(\phi) &= \Sigma M_z, \\
l_f\left(F_{y,fl}+F_{y,fr}\right)-l_r\left(F_{y,rl}+F_{y,rr}\right) &+ \\
-0.5B\left(F_{x,fl}-F_{x,fr}+F_{x,rl}-F_{x,rr}\right)+\cancel{\sum_{i=1}^{4}M_{zwi}} &= \Sigma M_z, \\
I_{xx}\ddot{\phi}-I_{xz}\dot{r}+K_{\phi_{eq}}\sin(\phi) &+ \\
+\left(C_{\phi f}+C_{\phi r}\right)\frac{B^2}{2}\dot{\phi}\cos(\phi)+M_{ARB,act} &= \Sigma M_x
\end{aligned}
$$

- Assumptions:
  - Self-aligning moment not accounted for
  - Rolling resistance and drag not considered
  - Vehicle symmetry along the X-Z plane

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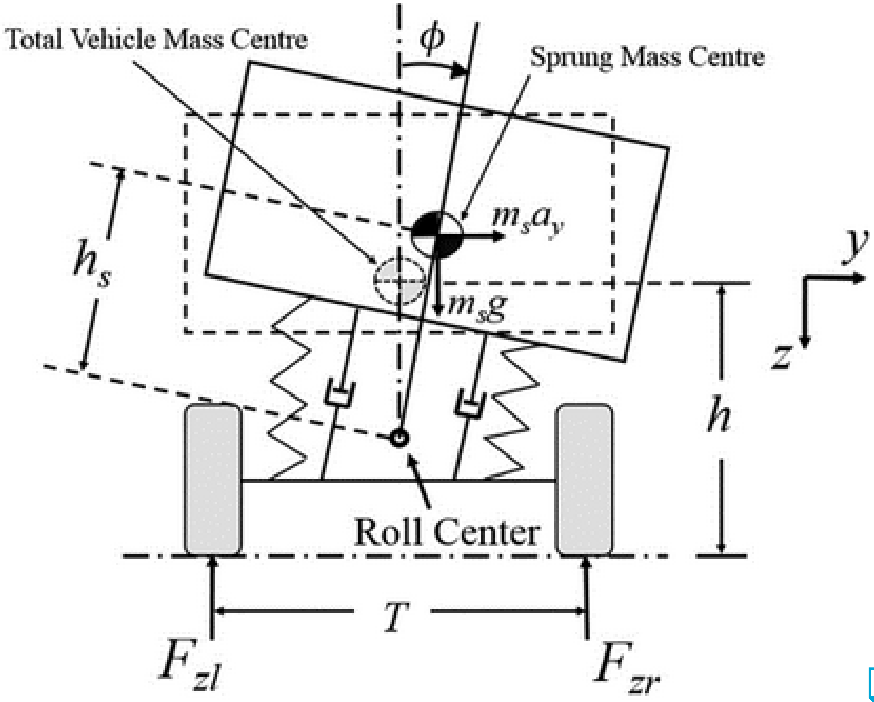
Vehicle Model



$$
\begin{aligned}
F_z^{long} &= m\frac{a_x}{2L}h_{cg} \\
F_z^{lat} &= \frac{mgh\sin(\phi) + ma_y h\cos(\phi)}{B} \\
F_{zfl} &= mg\frac{l_r}{2L} - F_z^{long} - F_{z,f}^{lat}, \\
F_{zfr} &= mg\frac{l_r}{2L} - F_z^{long} + F_{z,f}^{lat}, \\
F_{zrl} &= mg\frac{l_f}{2L} + F_z^{long} - F_{z,r}^{lat}, \\
F_{zrr} &= mg\frac{l_f}{2L} + F_z^{long} + F_{z,r}^{lat},
\end{aligned}
$$

- **Assumptions:**
  - **Pitch and heave motions neglected**
  - **Effect of unsprung mass not considered**

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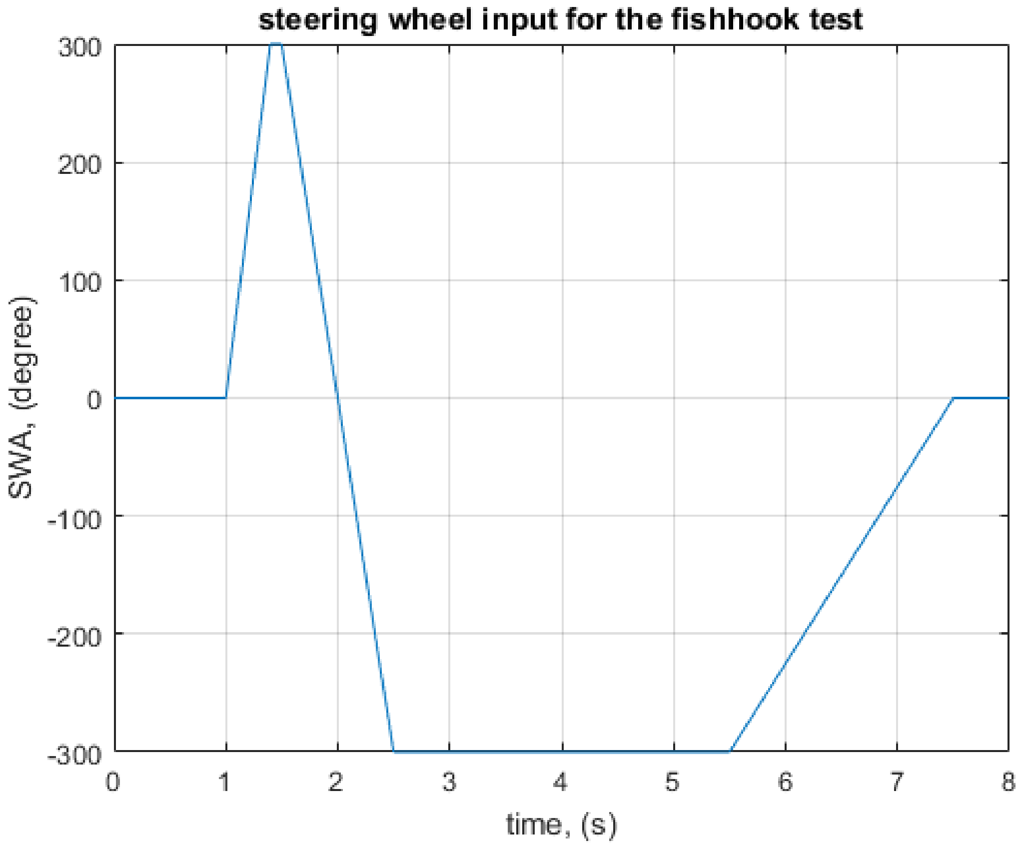
Fishhook Test

- **Objective**
  - **Evaluation of roll response of the vehicle through a fixed steering characteristic**
- **Procedure**
  - **Open loop test**
  - **Defined vehicle speed 40 km/h**
  - **Consists of a straight line, one**
  - **Left turn and sudden right turn**
- **Criteria**
  - **Vehicle handling and stability**
  - **Determine vehicle's roll-over behaviour**



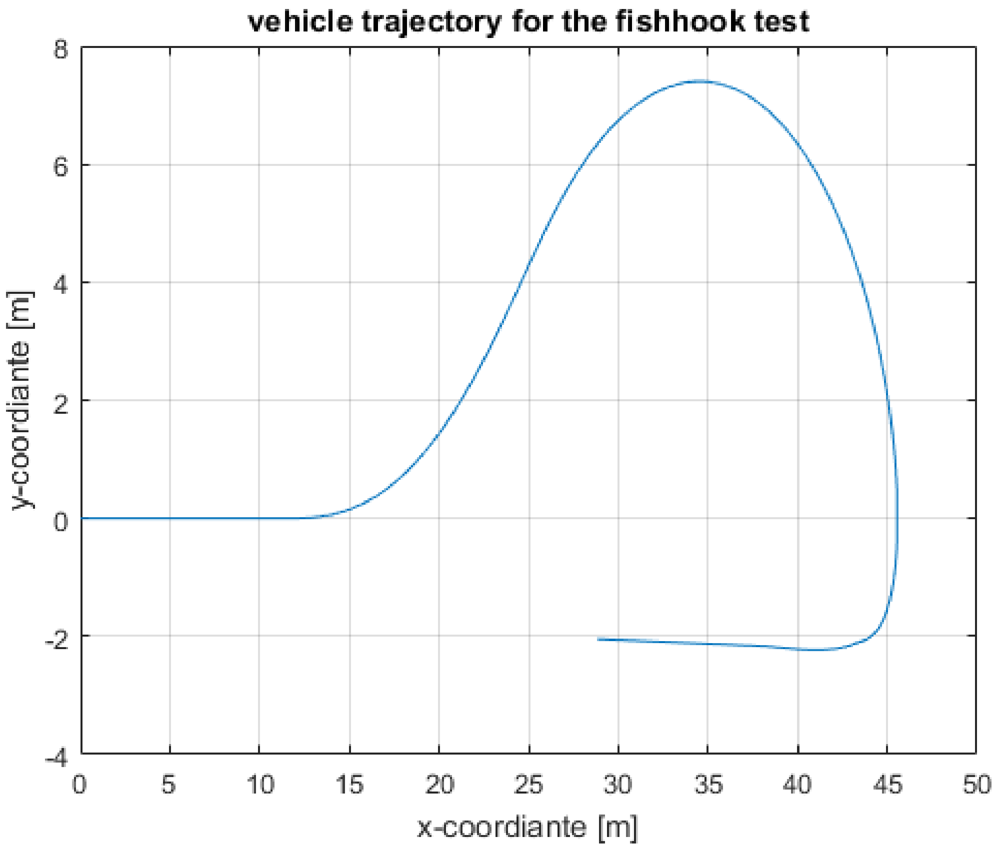
Simulation and Results

❑ Vehicle data

Symbol	Description	Value	Unit
I_{xx}	Inertia along x-axis	580	$[kgm^2]$
I_{zz}	Inertia along z-axis	3,240	$[kgm^2]$
I_{xz}	Coupling Inertia	50	$[kgm^2]$
r_w	Effective Wheel Radius	0.24	$[m]$
l_f	Front Wheelbase	1.253	$[m]$
l_r	Rear Wheelbase	1.508	$[m]$
B	Track	1.5	$[m]$
h_{cg}	Height of CoG	0.75	$[m]$
h_r	Height of Rear Roll Centre	0.4	$[m]$
h_f	Height of Front Roll Centre	0.4	$[m]$
C_{df}	Front Damping Coefficient	2,000	$[kg/s]$
C_{dr}	Rear Damping Coefficient	2,000	$[kg/s]$
K_f	Front Spring Stiffness	20,000	$[kg/s^2]$
K_r	Rear Spring Stiffness	20,000	$[kg/s^2]$
C_f	Front Cornering Stiffness	57,000	$[kg \cdot m/s^2]$
C_r	Rear Cornering Stiffness	47,000	$[kg \cdot m/s^2]$
C_κ	Front/Rear Long. Slip Coeff.	200,000	$[-]$
i_s	Steering Ratio	17	$[-]$

Symbol	Description	Value	Unit
K_{ϕ_f}	ARB_p Front Roll stiffness	10,000	$[kg \cdot m^2/s^2 \cdot rad]$
K_{ϕ_r}	ARB_p Rear Roll stiffness	7,500	$[kg \cdot m^2/s^2 \cdot rad]$
K_p	Proportional Gain	$1.7 \cdot 10^6$	$[-]$
a	Zero of G(s)	3	$[1/s]$
b	Zero of G(s)	1	$[1/s]$
c	Pole of G(s)	9	$[1/s]$
d	Pole of G(s)	7	$[1/s]$

❑ Fishhook Trajectory



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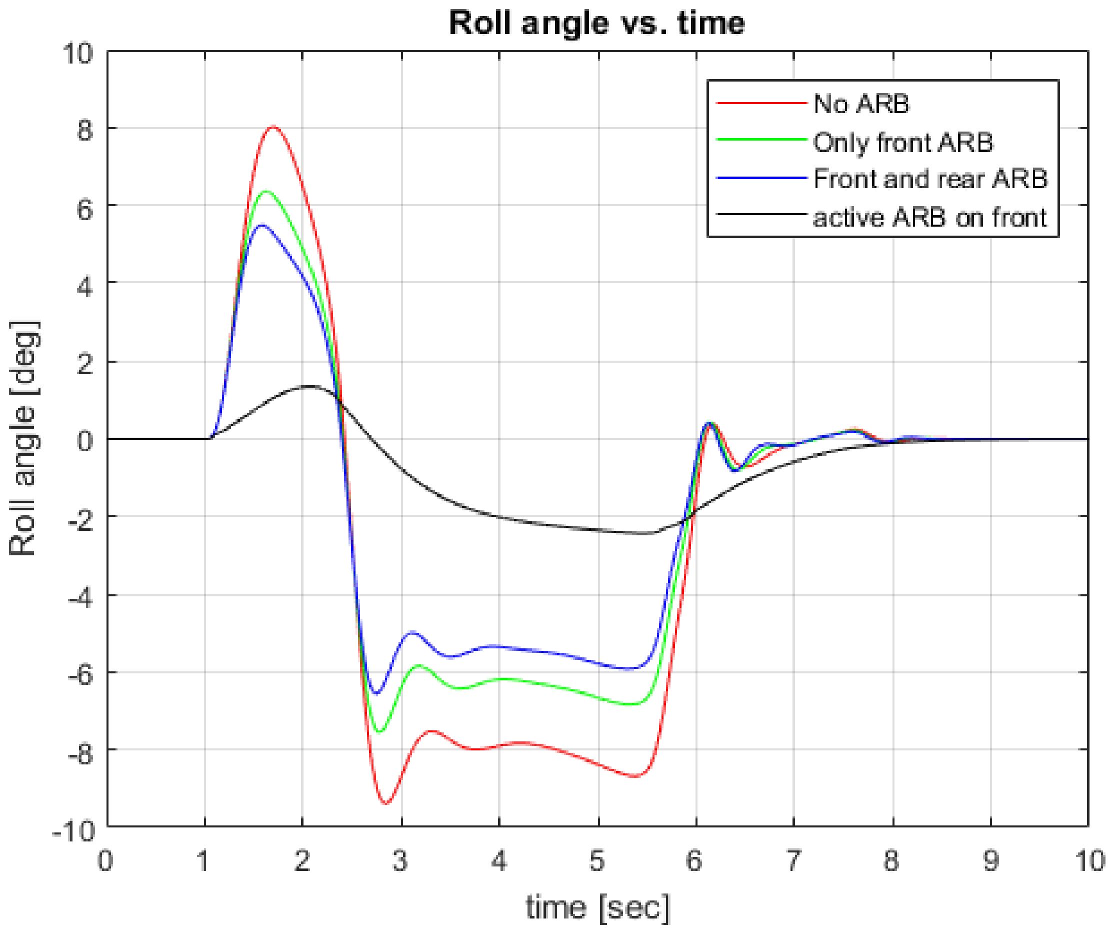
Simulation and Results

- Roll angle
- Ride comfort



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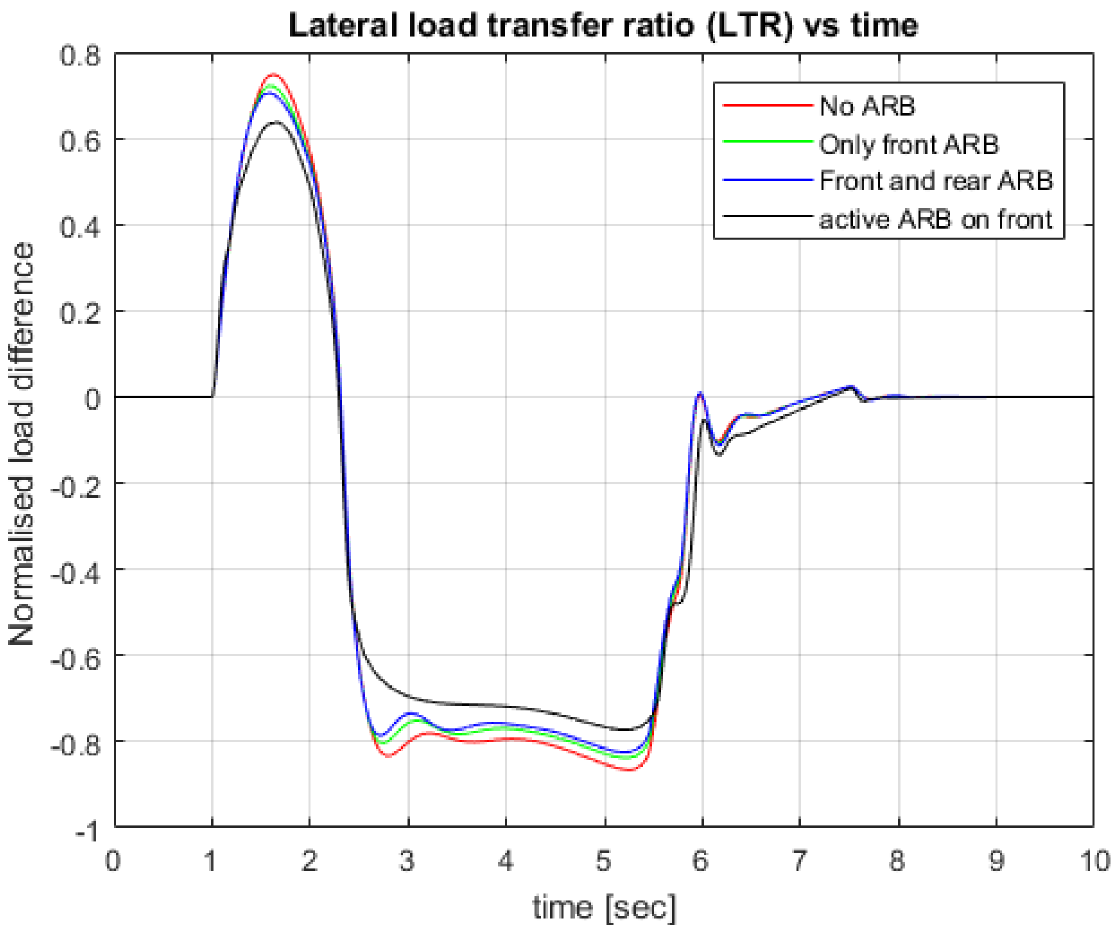
Simulation and Results

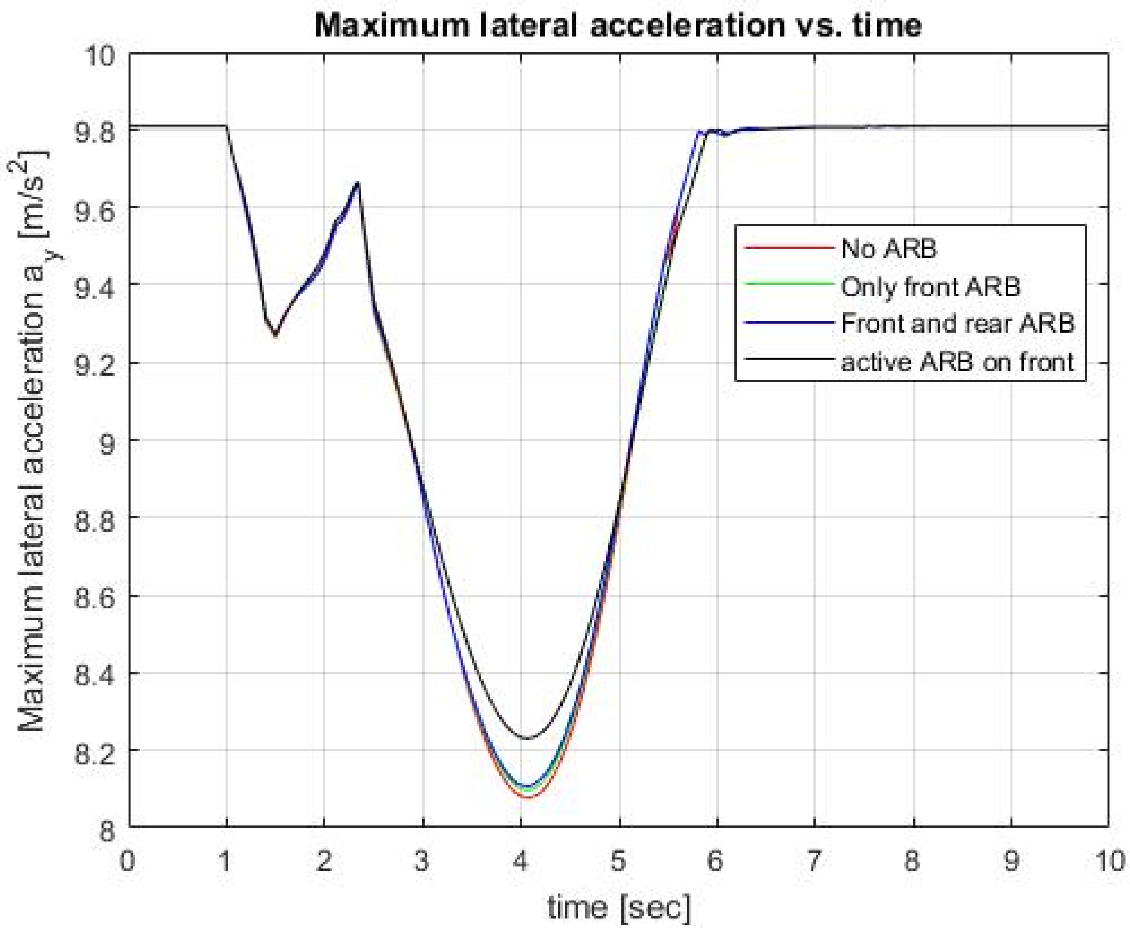
- Front axle normal load transfer
- Road holding

$$LTR = \frac{F_{zr} - F_{zl}}{F_{zr} + F_{zl}}$$



Simulation and Results

- Maximum Achievable Lateral Acceleration
- Ride handling



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Conclusion

- Incorporation of an ARB improves the vehicle roll-over stability characteristics
  - Ride comfort
  - Road holding
  - Ride handling

- Inclusion of ARB reduces lateral load transfer resulting in an improvement of vehicle handling

- The implementation of an ARB increases the average lateral force that can be generated during a cornering maneuvre, therefore increasing the maximum achievable lateral acceleration

- Increases driver confidence

- Implementation of a simple control law amplifies the capability of the ARB to decrease the overall body-roll (A-ARB)

Thank You!!!

Extra slides (1): Vehicle Parameters

Symbol	Description	Value	Unit
I_{xx}	Inertia along x-axis	580	$[kgm^2]$
I_{zz}	Inertia along z-axis	3,240	$[kgm^2]$
I_{xz}	Coupling Inertia	50	$[kgm^2]$
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Extra slides (2): Effect on Understeer Gradient

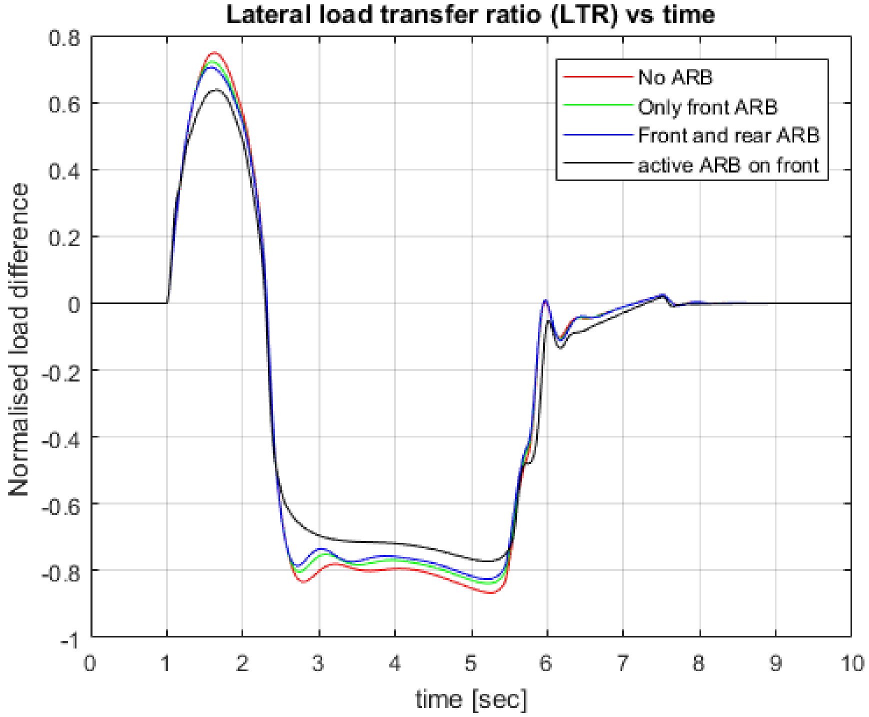
- If $K_{\phi f} \uparrow, K_{\phi r} =$, then $F_{z,f}^{lat} \uparrow$, thus more understeer

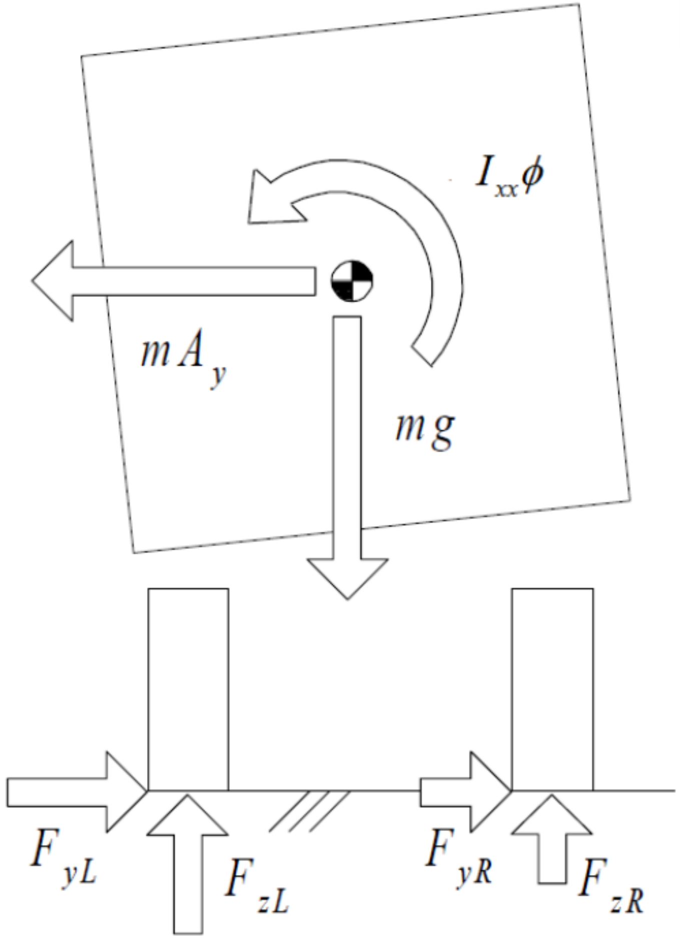
$$F_{z,f}^{lat} = \frac{m_a a_y}{B}\left(\frac{l_r}{L}h_f + \frac{K_{\phi f}h}{K_{\phi f} + K_{\phi r} - m_a gh}\right)$$

$$F_{z,r}^{lat} = \frac{m_a a_y}{B}\left(\frac{l_f}{L}h_r + \frac{K_{\phi r}h}{K_{\phi f} + K_{\phi r} - m_a gh}\right)$$

Extra slides (3): Load Transfer Ratio

- $LTR = \frac{F_{zr} - F_{zl}}{F_{zr} + F_{zl}}$





Extra slides (4): PDD Controller

$$\boldsymbol{G(s) = 17 \cdot 10^5 \, \frac{(s+1)(s+3)}{(s+7)(s+9)}}$$

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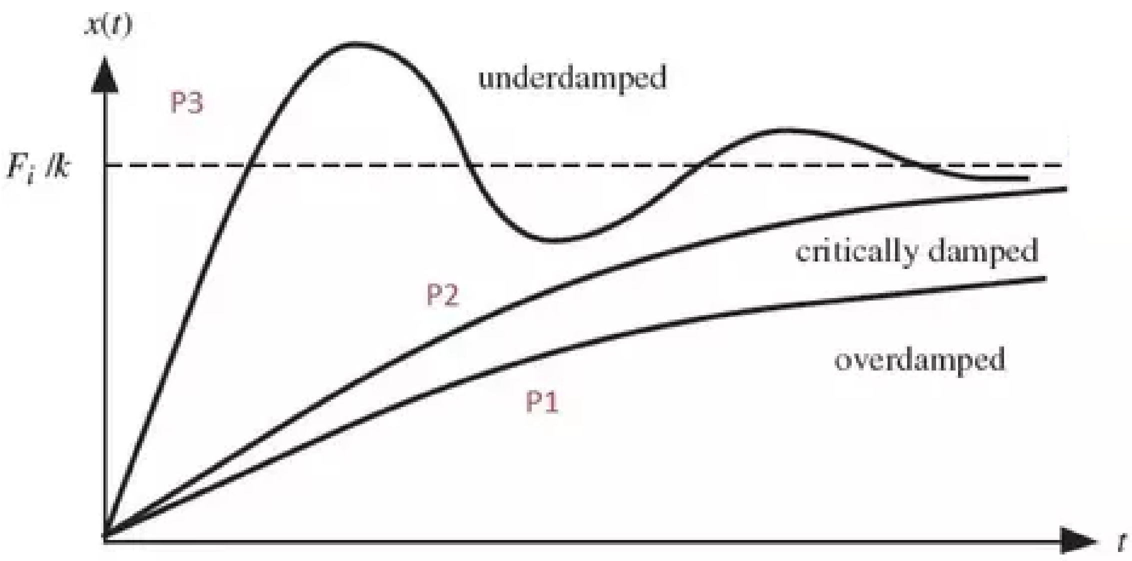
Extra slides (5): Transient response



Extra slides (6): Normal Load Transfer Equations

$$
\begin{aligned}
F_{zfl} &= mg\frac{l_r}{2L} - F_z^{long} - F_{z,f}^{lat} \\
F_{zfr} &= mg\frac{l_r}{2L} - F_z^{long} + F_{z,f}^{lat} \\
F_{zrl} &= mg\frac{l_f}{2L} + F_z^{long} - F_{z,r}^{lat} \\
F_{zrr} &= mg\frac{l_f}{2L} + F_z^{long} + F_{z,r}^{lat} \\
F_z^{long} &= m\frac{a_x}{2L}h_{cg} \\
F_z^{lat} &= \frac{mgh\sin(\phi) + ma_y h\cos(\phi)}{B}
\end{aligned}
$$

$$h = \frac{h_{cg} - h_{rc}}{\cos(\phi)}.$$