interactIVe

Accident avoidance by active intervention for Intelligent Vehicles

Vehicle dynamics modeling and simulation for active safety development in MATLAB / Simulink

Mathias Lidberg

Morteza Hassanzadeh

InteractIVe Summer School

4-6 July, 2012

Agenda

- About Me
- Vehicle Dynamics Research at Chalmers
- Introduction
  - Importance of Tires: Friction Circle
  - Target Applications and Research Areas
  - Lecture: Pre requisites/Aim/Learning Outcomes/Focus
  - Intertwined Lecture & Tutorial
- Module 1: Vehicle Modeling for Planar Dynamics
- Module 2: Tire Modeling
- Module 3: Vehicle Handling and Stability
- Module 4: Heavy Vehicles
- Module 5: Vehicle Path and Stability Control
- Experimental Vehicle Dynamics
- Literature
- Wrap Up

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About Me

- 2004: Ph.D. thesis in Mechanics on design of optimal control processes for closed-loop chain SCARA-like robots.
- 2004: Assignment of supporting the re-establishment of the vehicle dynamics area at Applied Mechanics.
- 2007: Assistant Professor in vehicle dynamics.
- 2012: Associate Professor in vehicle dynamics

Main Research Areas:

- Path and stability control of heavy vehicles
- Integrated powertrain and chassis control
- Optimal control applications in vehicle dynamics

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Vehicle Dynamics Group at Chalmers

- Professor Bengt Jacobson
- Associate Professor Mathias Lidberg
- Adjunct Professor Gunnar Olsson (20%), formerly with Saab
- Post Doc Fredrik Bruzelius (75%), VTI
- Guest Researcher Professor Tim Gordon, University of Michigan

- PhD Student Sogol Kharrazi (Volvo Group)
- PhD Student Derong Yang (Volvo Cars)
- Project Assistant Morteza Hassanzadeh
- Industry PhD Student Ulrich Sander (Autoliv)
- Industry PhD Student Adithya Arikere (eAAM)
- Industry PhD Student Peter Nilsson (Volvo)
- Industry PhD Student Kristoffer Tagesson (Volvo)

Vehicle Dynamics Group at Chalmers

Integrated Braking and Steering for Heavy Vehicle Combinations (IBS*Truck*)

- The existing brake based Electronic Stability Control (ESC) for heavy vehicles is limited to first unit control.
- The objective of this project is to extend the stability control to all units by exploiting additional actuators such as active steering.

PhD student: Sogol Kharrazi

Partner/Sponsor: Volvo3P/IIVSS

Advisers: Mathias Lidberg, Jonas Fredriksson

Vehicle Dynamics Group at Chalmers

Integrated Braking and Steering for Heavy Vehicle Combinations (IBS*Truck*)

- Testing at MIRA Proving Ground (Dancing Elephants)

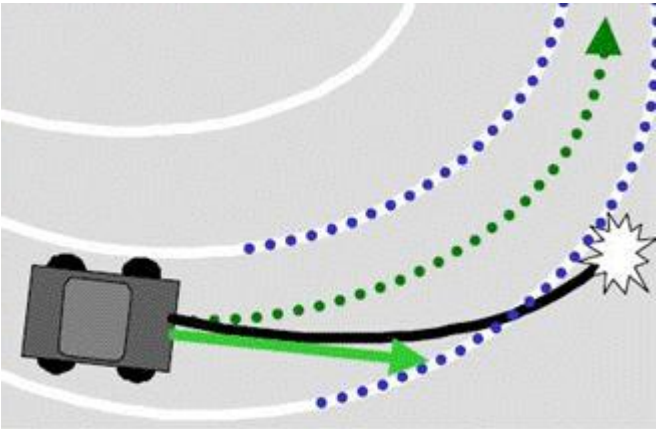
⟵ Active Steering ⟶

interactive

Vehicle Dynamics Group at Chalmers

Optimal Path Recovery for Over-Speeding in Curves

- Overspeed in curves leads to a path outside the intended path (off-tracking) and may lead to a run-off-road (ROR) crash
- According to report DOT HS 811 232 (FARS) discussing fatal single-vehicle ROR crashes:
    - Around 1/3 of the crashes occurred in a turn.
    - Nearly 1/2 of the crashes involved speeding
    - ROR crashes are more likely to occur in adverse weather conditions



Industry PhD student: Matthijs Klomp

Partner/Sponsor: Saab Automobile/IVSS

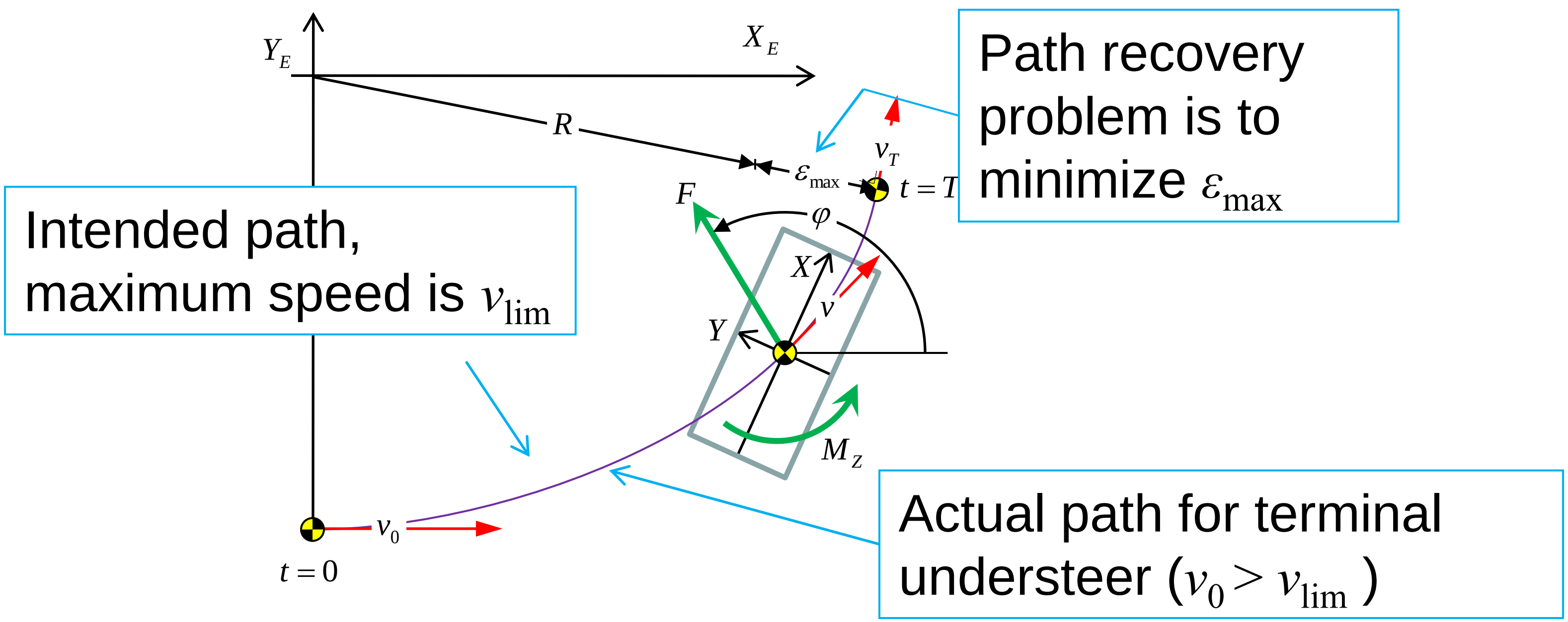
Advisers: Mathias Lidberg, Tim Gordon

interactive

Vehicle Dynamics Group at Chalmers

Optimal Path Recovery for Over-Speeding in Curves

An optimal control problem is formulated to **minimize the maximum off tracking**, i.e. the off-tracking when the velocity vector is parallel to intended path).



Vehicle Dynamics Group at Chalmers

Optimal Path Recovery for Over-Speeding in Curves
Initial Experiments

No Control

Parabolic Path Recovery (PPR)

interactive

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The Vehicle Dynamics Area

- Here, vehicle dynamics is defined as the gross (mainly) planar motion of road vehicles
- Research focus on safety but also performance and efficiency
- Mainly analysis and simulations but also experimental verification of theoretical results

The Importance of the Tire: The Friction Circle

The utilization of the vehicle road contact (the friction circle) for tire force generation has been increasing gradually since the beginning of the automobile era.

- The invention of the pneumatic tire and the development of more powerful actuators resulted in higher speeds and larger accelerations.
- Wheel slip control (ABS/TCS) improved the brake/acceleration performance and maneuverability during braking/acceleration, which paved the ground for electronic stability control (ESC).
- Today, the (electrified) propulsion system will be used for (regenerative) braking and also for direct yaw-moment control (DYC) for improved performance, maneuverability, agility and stability

Target Applications and Research Areas

- **Classical Vehicle Dynamics** (tire modeling, aerodynamics, power train/suspension design, novel components …)
- **Motion Stability Control** (yaw stability control, roll stability control, robust yaw control, heavy articulated vehicles, post impact stability control …)
- **Computer Aided Driving Systems** (adaptive cruise control, lane keeping assistance, forward collision warning, braking assistance…)

Prerequisites

Basics:

- Mechanics (2D Newton)
- Control Theory
- Vehicle Dynamics

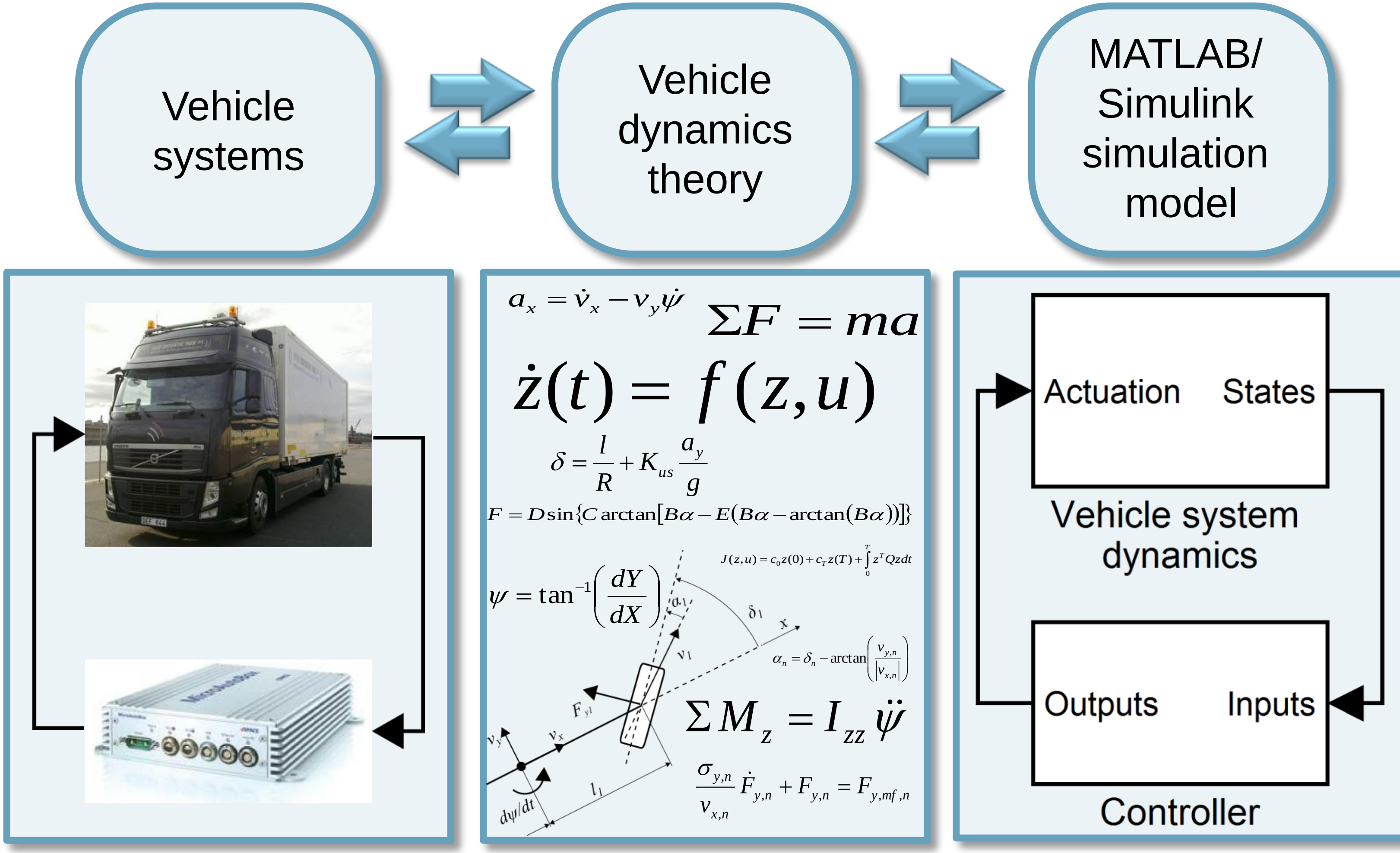
Computer Tools:

- Some Programming Skills

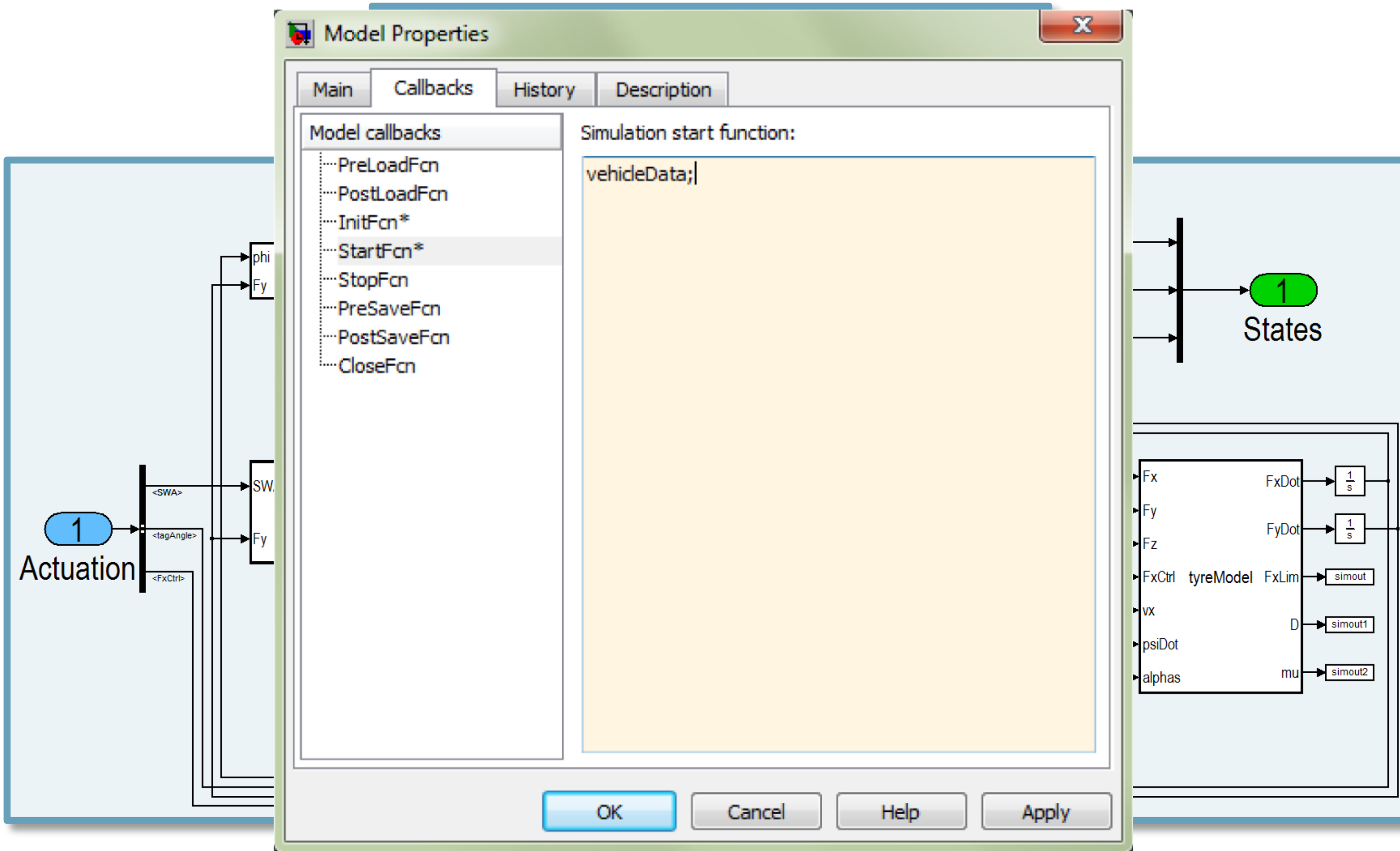
Scope and Aim

- This lecture is based on a 7-week course at Chalmers University of Technology.
- In this lecture the focus is put on the basic understanding of modeling and analysis of the controlled planar dynamics of road vehicles for active safety development
- The lecture also aims to give a tutorial of vehicle system dynamics modeling and control in Matlab/Simulink

Intertwined lecture and tutorial overview



Intertwined lecture and tutorial overview



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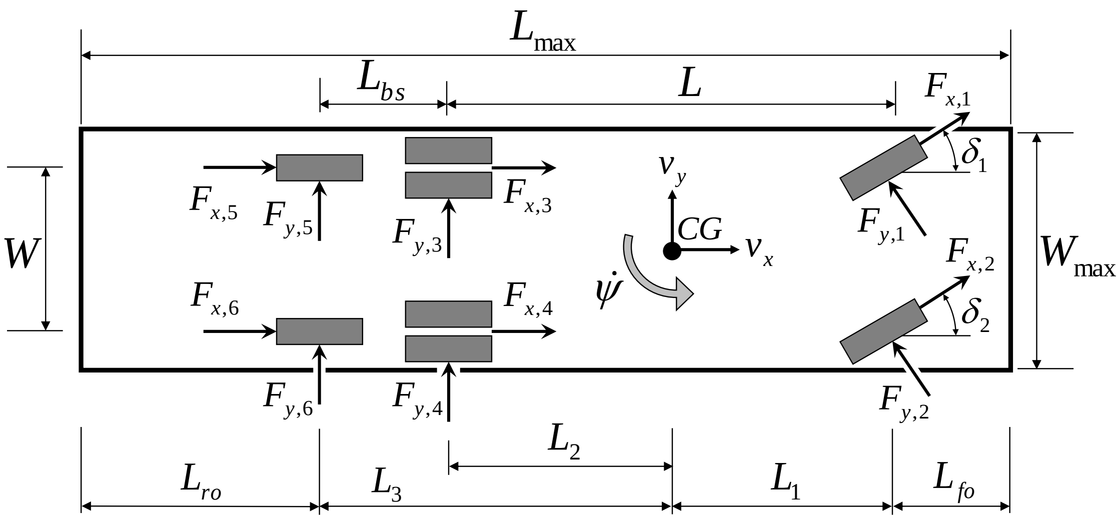
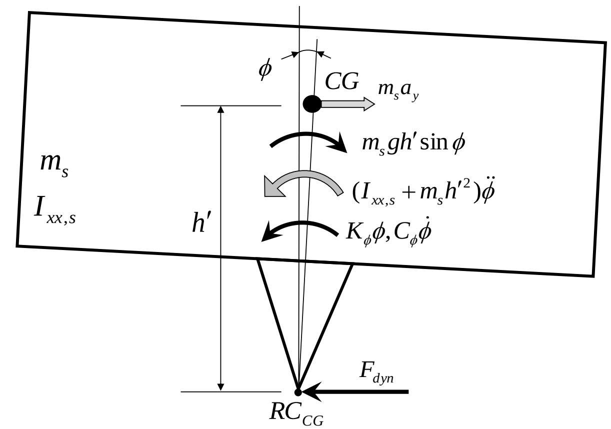
Module 1: Vehicle Modeling for Planar Dynamics

- Vehicle simulation model (longitudinal, lateral, yaw, roll)





Module 1: Vehicle Modeling for Planar Dynamics

- The planar nonlinear two track model:

$$m(\dot{u} - rv) = \sum F_x,$$
$$m(\dot{v} + ru) = \sum F_y,$$
$$I_z \dot{r} = \sum M_z$$

- where the sum of the forces and moments are:

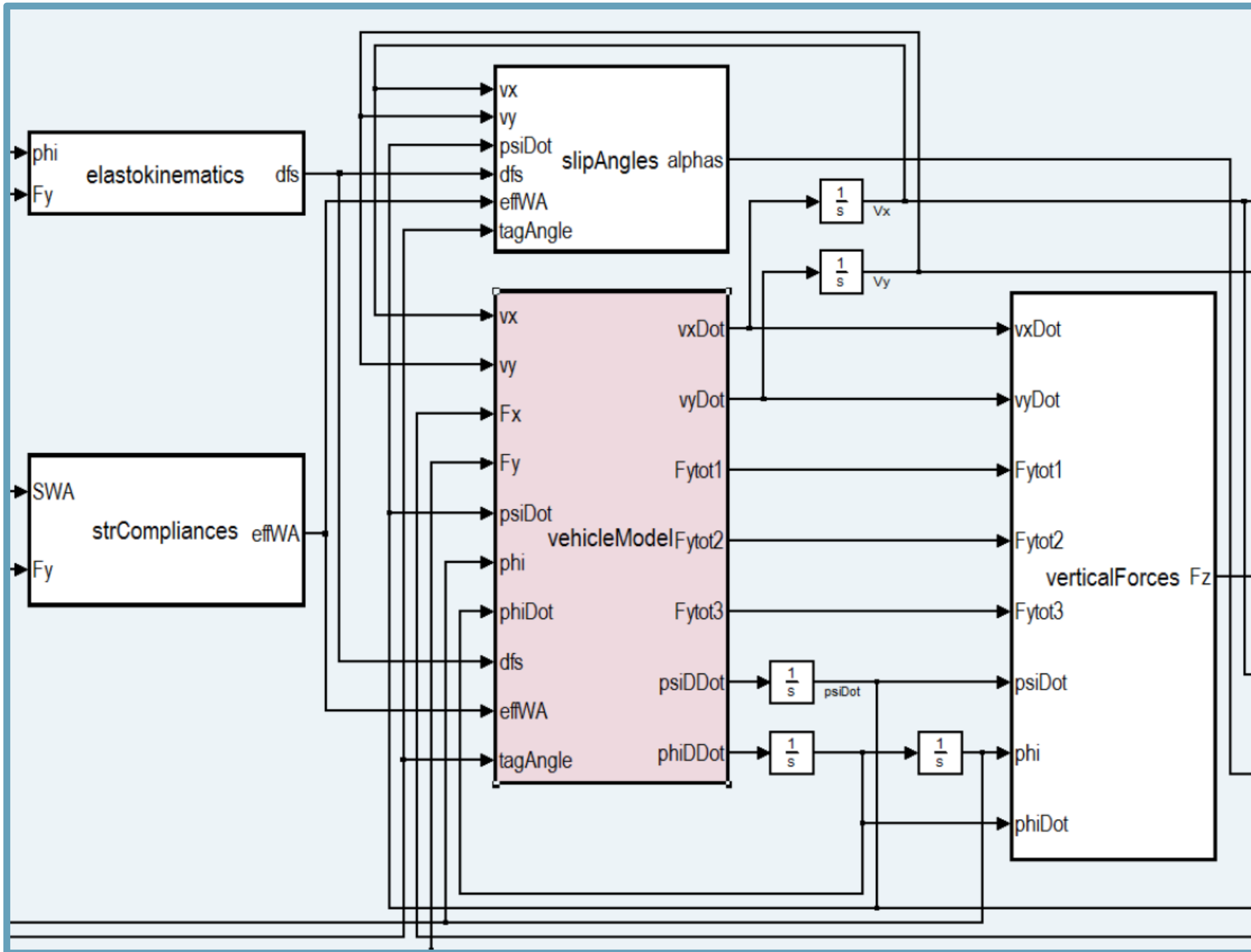
$$\sum F_x = F_{x1L} + F_{x1R} - (F_{y1L} + F_{y1R})\,\delta_1 + F_{x2L} + F_{x2R} - (F_{y2L} + F_{y2R})\,\delta_2,$$
$$\sum F_y = (F_{x1L} + F_{x1R})\,\delta_1 + F_{y1L} + F_{y1R} + (F_{x1L} + F_{x1R})\,\delta_1 + F_{y2L} + F_{y2R},$$
$$\sum M_z = s_1 F_{x1L} + a F_{x1L}\delta_1 + \ldots$$

- the slip angles for all wheels

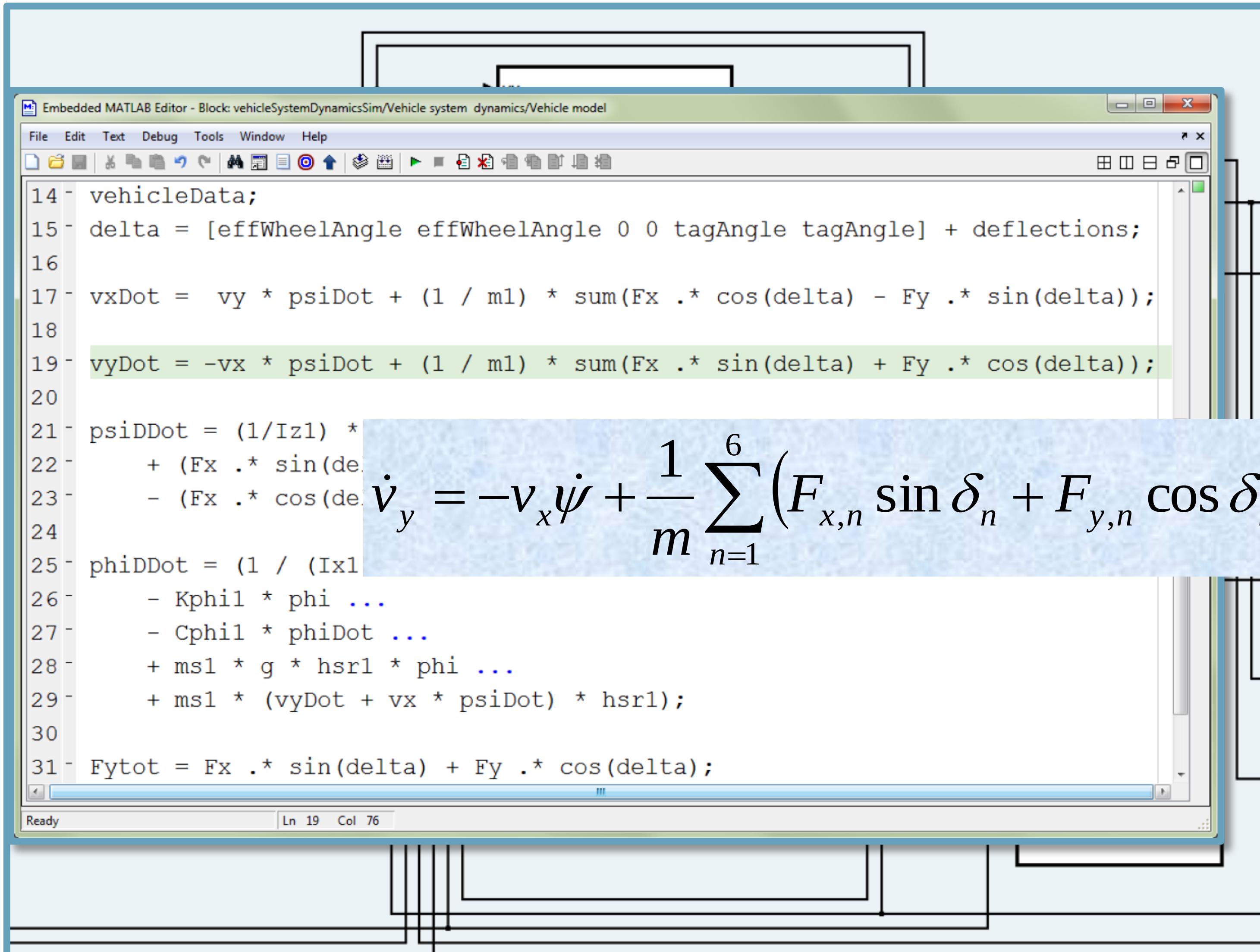
$$\tan(\delta_1 - \alpha_{1L}) = \frac{v_{y1L}}{v_{x1L}} = \left(\frac{v + ar}{u + s_1 r}\right),$$

- the tire forces from suitable tire model, e.g. Pacejka Magic Formula

Module 1: Vehicle Modeling for Planar Dynamics / Tutorial



Module 1: Vehicle Modeling for Planar Dynamics / Tutorial



$$\dot{v}_y = -v_x \dot{\psi} + \frac{1}{m} \sum_{n=1}^{6} \left(F_{x,n} \sin \delta_n + F_{y,n} \cos \delta_n \right)$$

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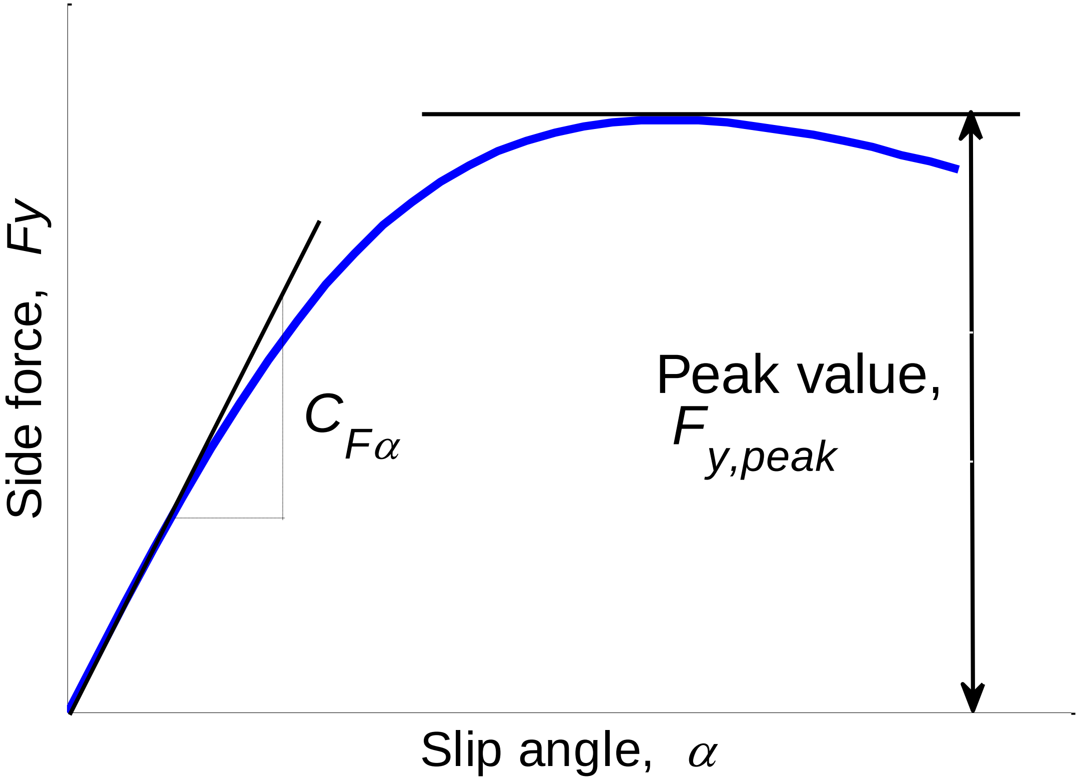
Module 2: Tire Modeling / Tutorial

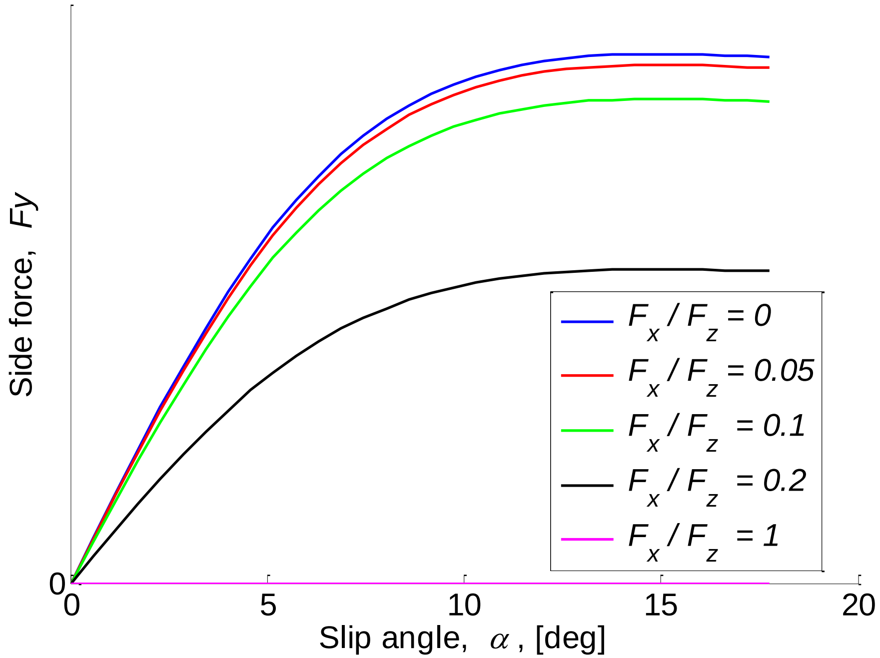
- Tire characteristics are of crucial importance



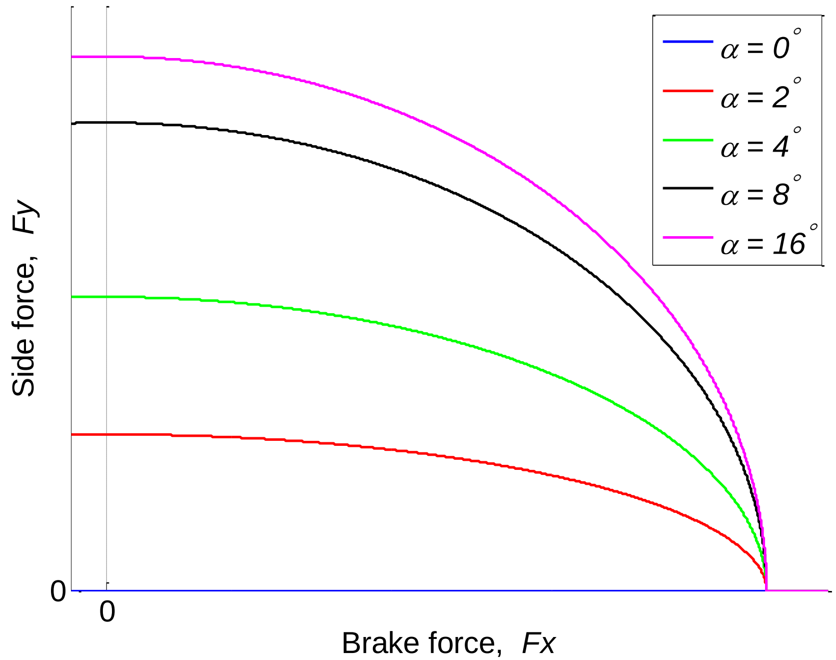
Module 2: Tire Modeling / Tutorial

- Combined slip characteristics

Variation of lateral force vs. slip angle for different normalized brake forces



Variation of lateral force vs. brake force for different slip angles

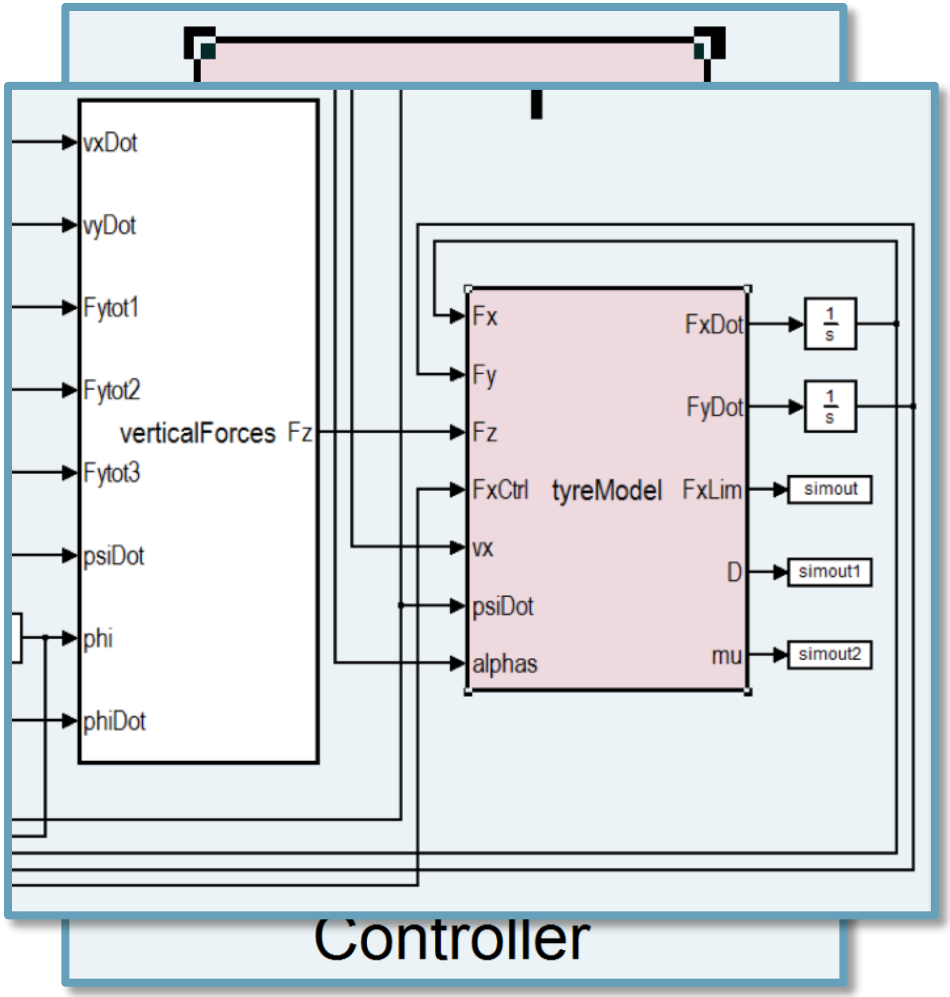


Module 2: Tire Modeling / Tutorial

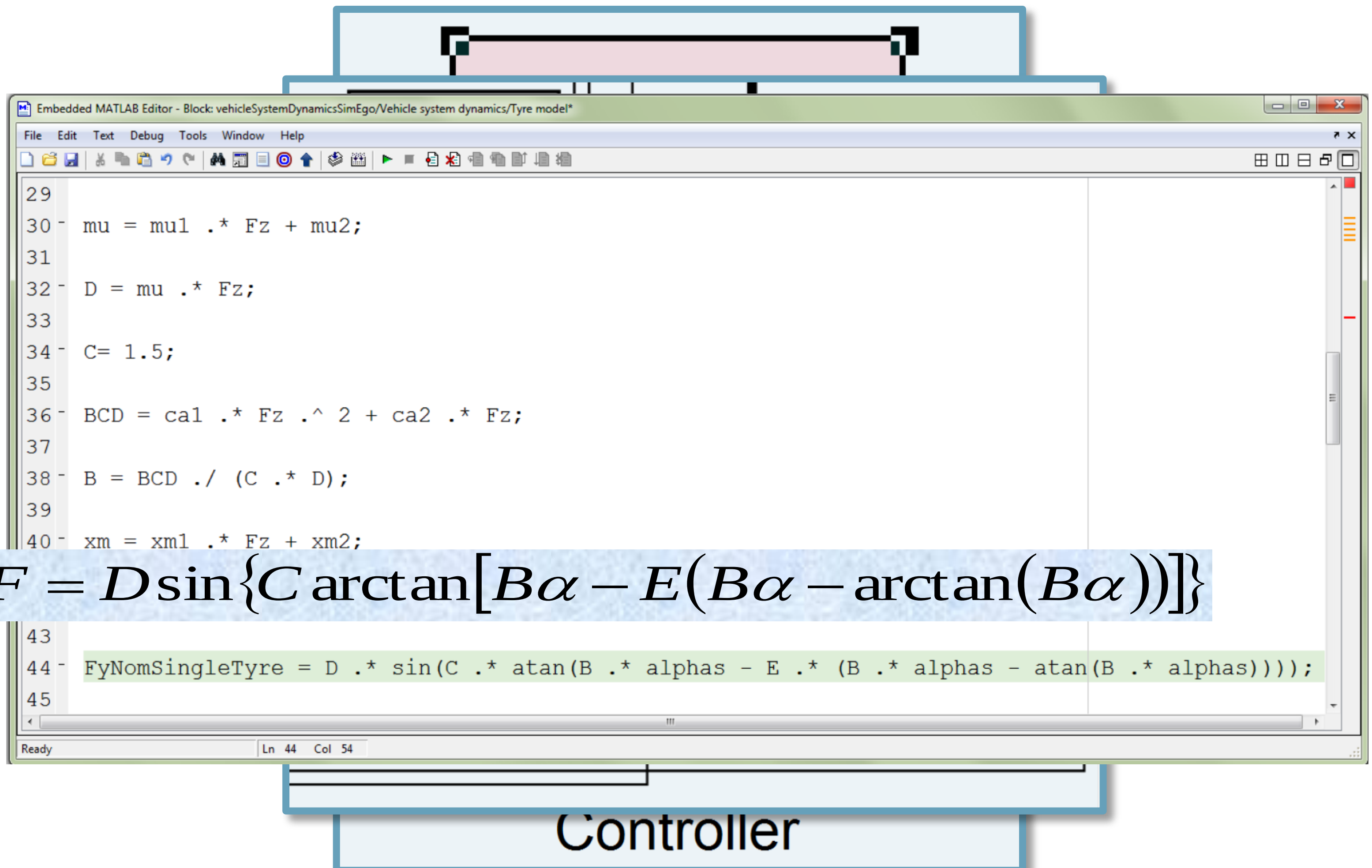
- The Tire Magic Formula with Longitudinal Force as Input

$$F_y = \sqrt{(\mu F_z)^2 - F_x^2} \sin\left(C \arctan\left(B\alpha - E\left(B\alpha - \arctan\left(B\alpha\right)\right)\right)\right),$$
$$-\mu F_z \cos(\alpha) \leq F_x \leq \mu F_z.$$

Module 2: Tire Modeling / Tutorial



Module 2: Tire Modeling / Tutorial



$$F = D\sin\{C\arctan[B\alpha - E(B\alpha - \arctan(B\alpha))]\}$$

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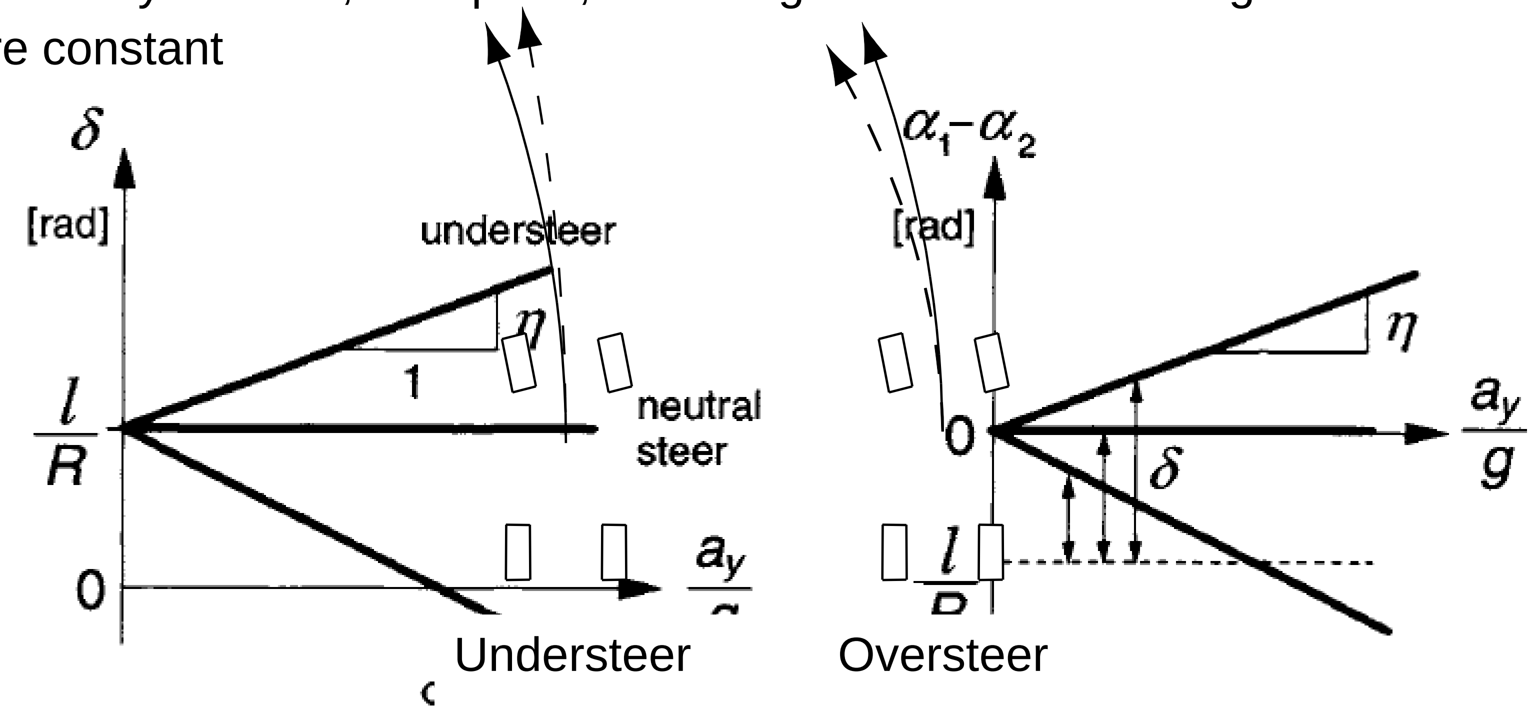
Module 3: Vehicle Handling and Stability

Steady state cornering solutions and handling diagram (small and large lateral accelerations)

For every solution, the speed, cornering radius and steer angle are constant



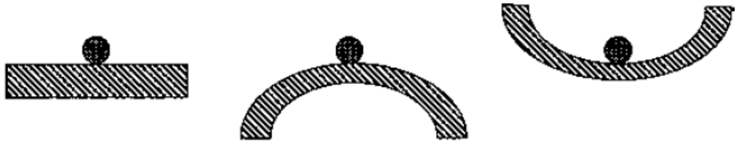
Understeer Oversteer

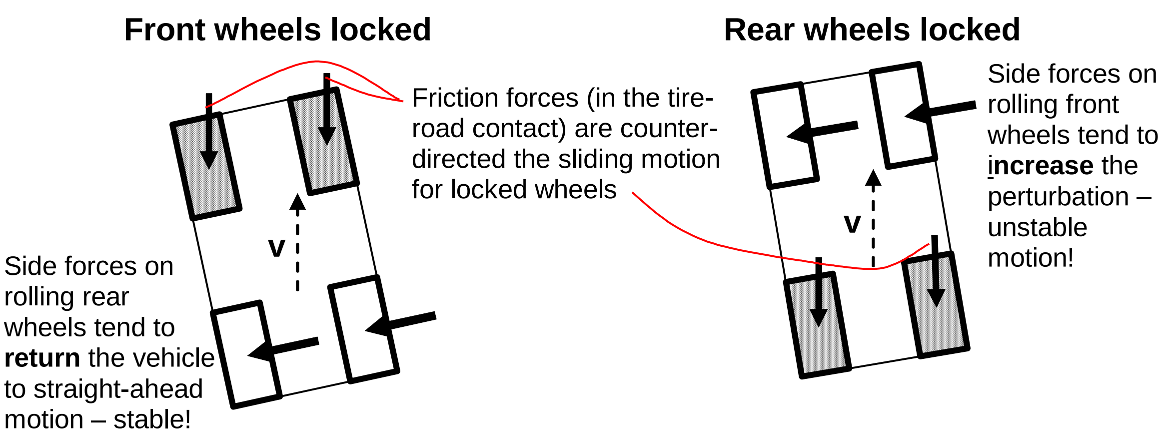
From Pacejka: The steer angle versus lateral acceleration. (Handling Diagram).

Module 3: Vehicle Handling and Stability

Stability of yaw motion for small deviations with respect to steady-state motion (small and large lateral accelerations)

Is there a resisting yaw moment?



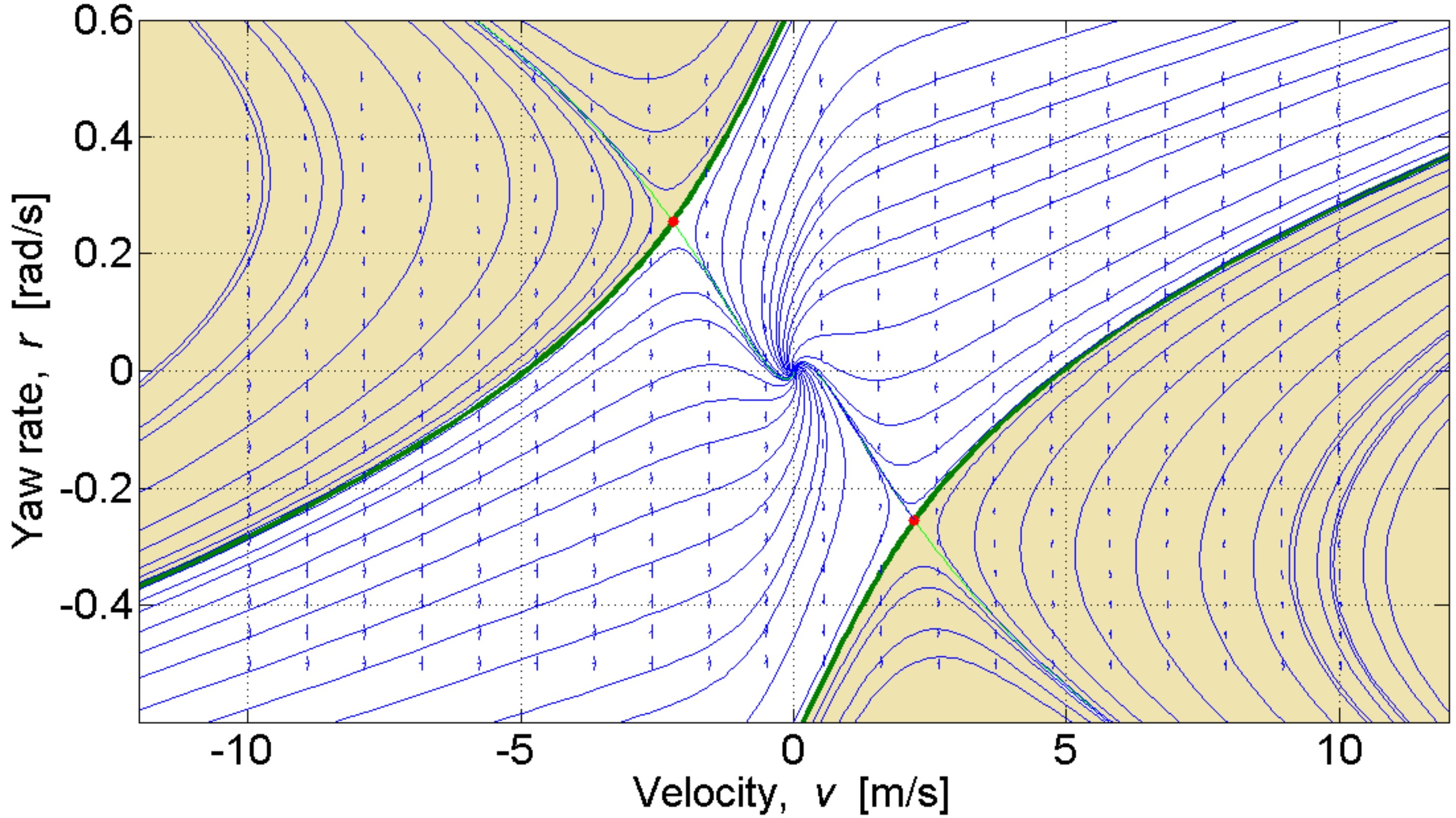


Understeered
Stable

Oversteered
Unstable
(Critical speed)

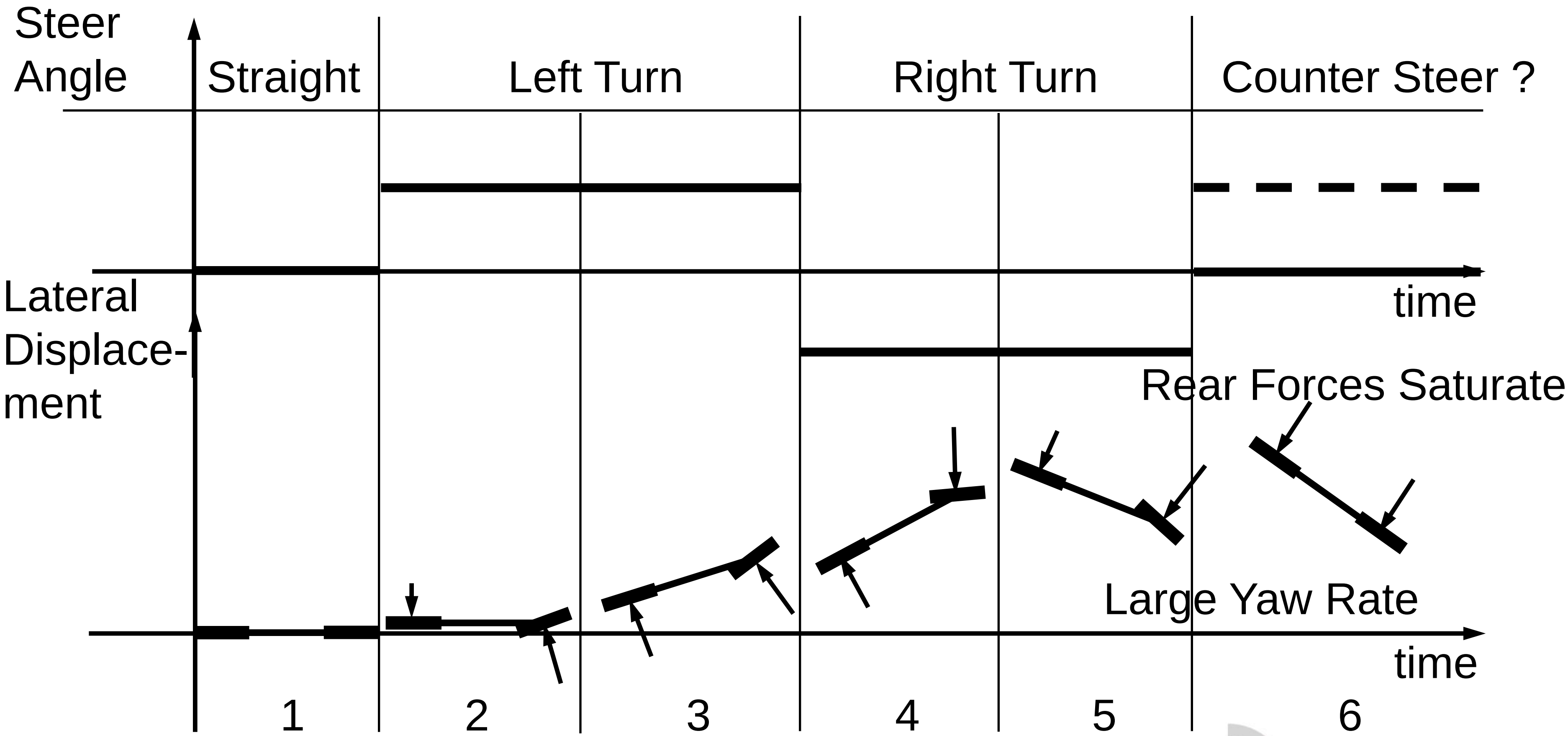
Module 3: Vehicle Handling and Stability

Stability of motion for large deviations with respect to steady-state motion (small and large lateral accelerations)



Module 3: Vehicle Handling and Stability

How to make a vehicle unstable for large deviations from steady state cornering using the pendulum effect (a Scandinavian Flick).



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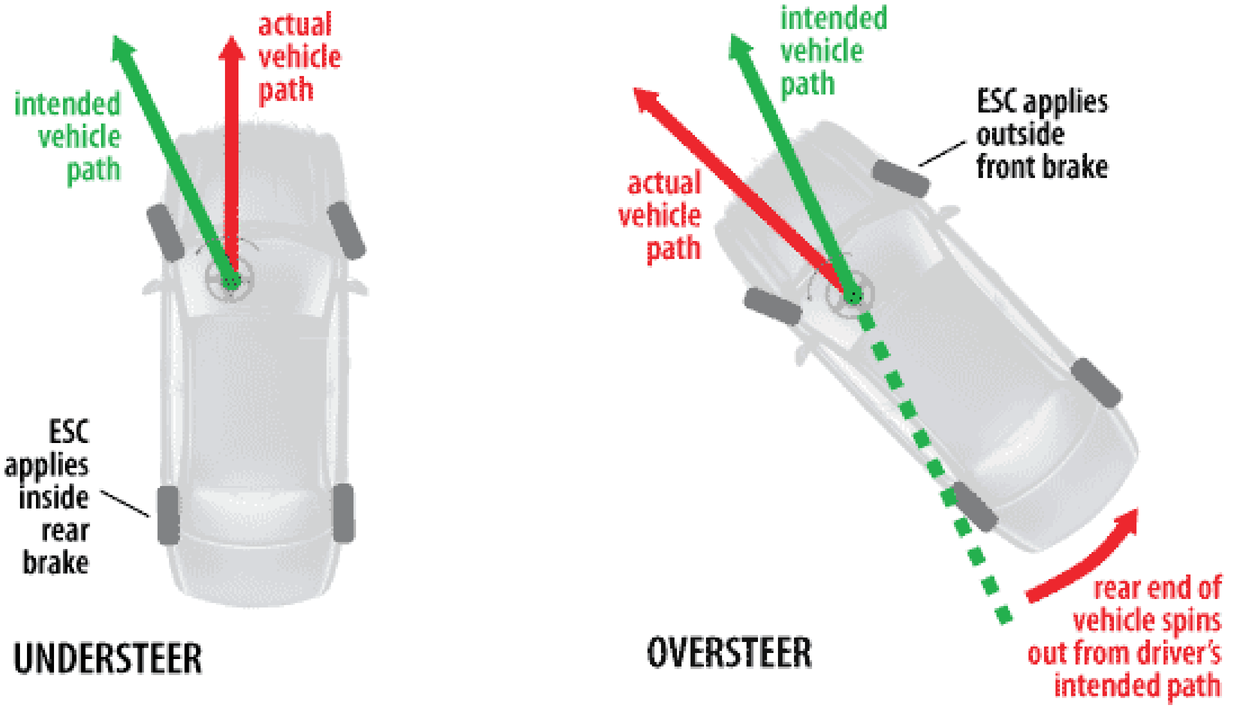
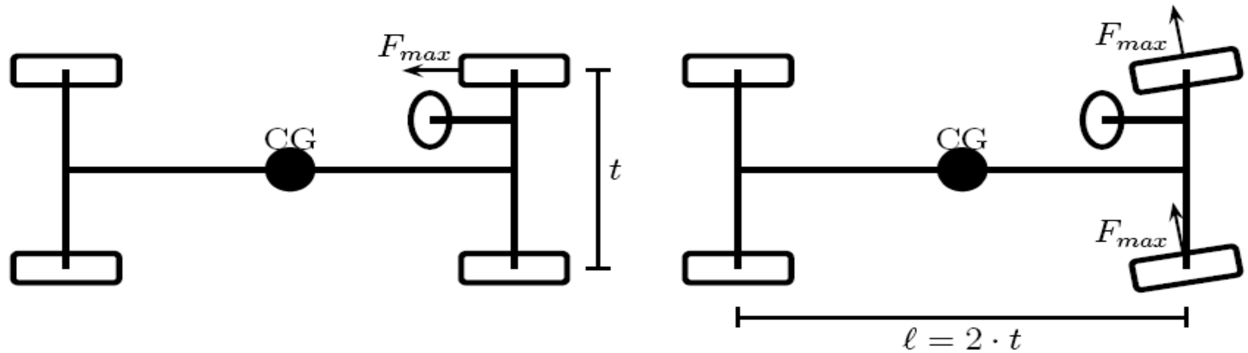
Module 5: Vehicle Path and Stability Control

Brake based Electronic Stability Control (ESC) applies a resisting yaw moment by braking individual wheels to counteract the stability problem



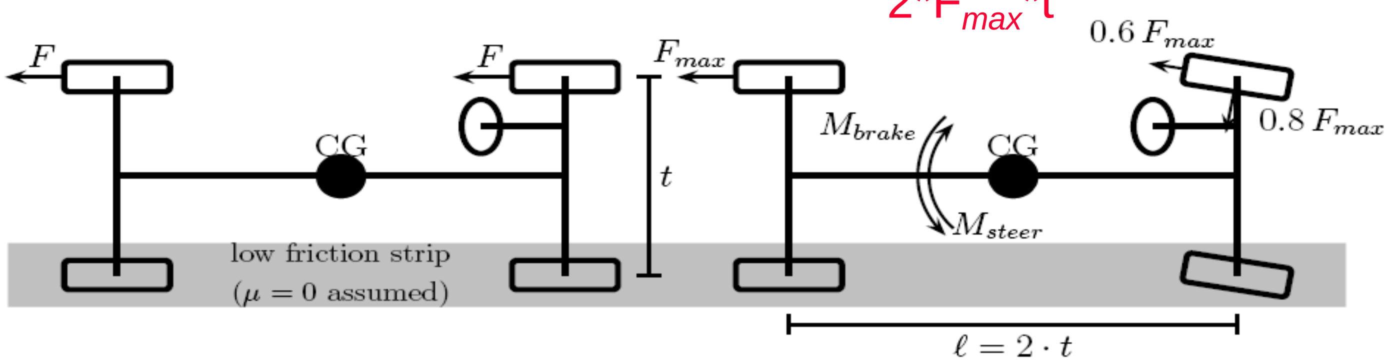
Module 5: Vehicle Path and Stability Control

Steering based stability control also applies a yaw moment



$M_{brake} = F_{max}*t/2$

$M_{steer} = 2*F_{max}*t$

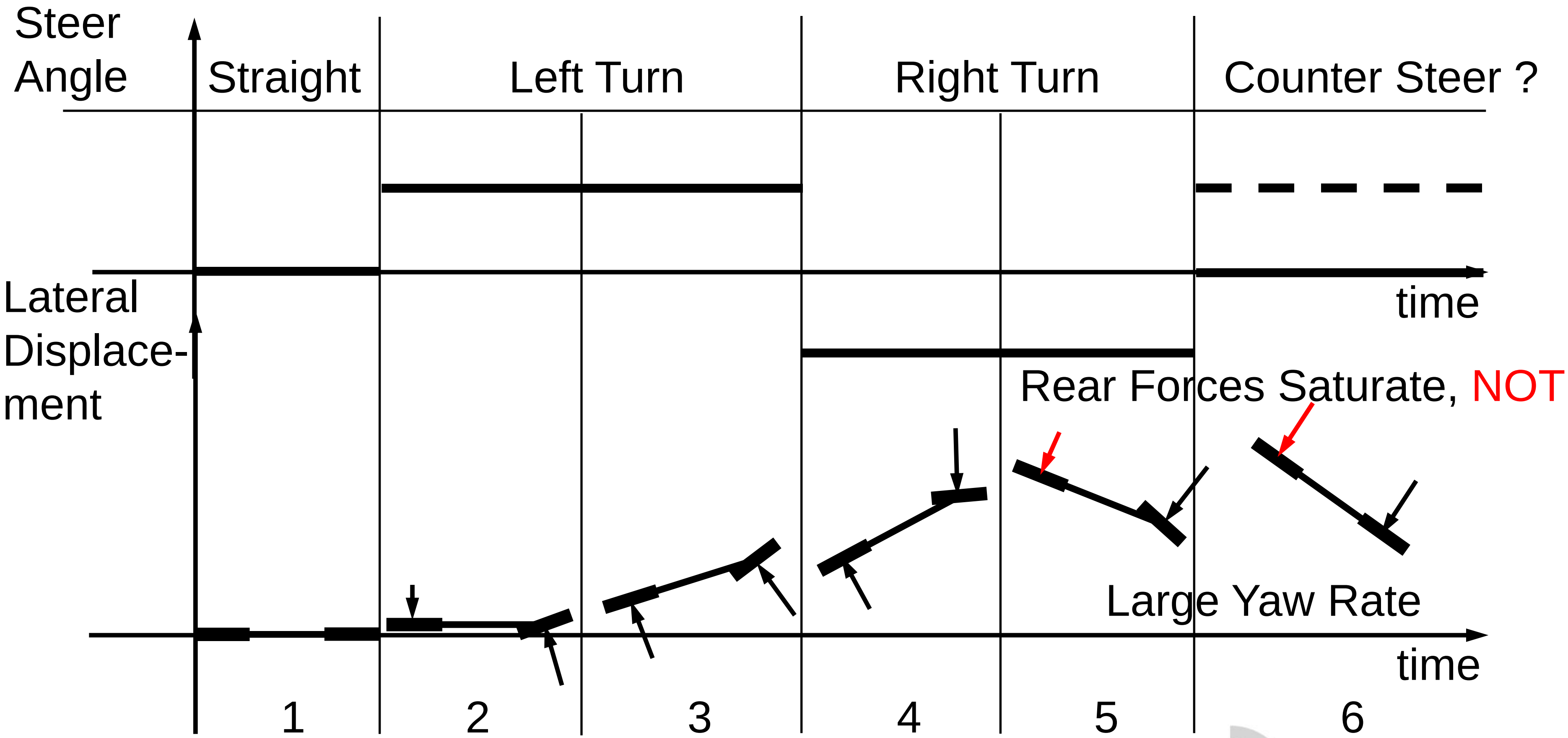


$F_{deceleration} = 0$

$F_{deceleration} = 1.6F_{max}$

Module 5: Vehicle Path and Stability Control

How to make a vehicle unstable for large deviations from steady state cornering using the pendulum effect (a Scandinavian Flick).



Module 5: Vehicle Path and Stability Control

Integrated Braking and Steering for Heavy Vehicle Combinations (IBS*Truck*)

- Testing at MIRA Proving Ground (Dancing Elephants)

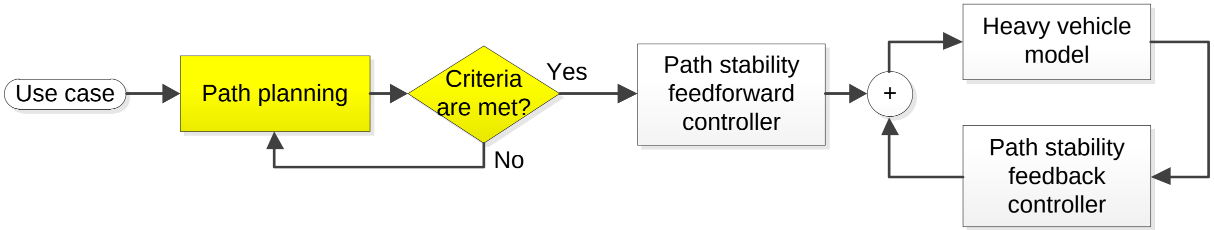
⟵ Active Steering ⟶

interactive

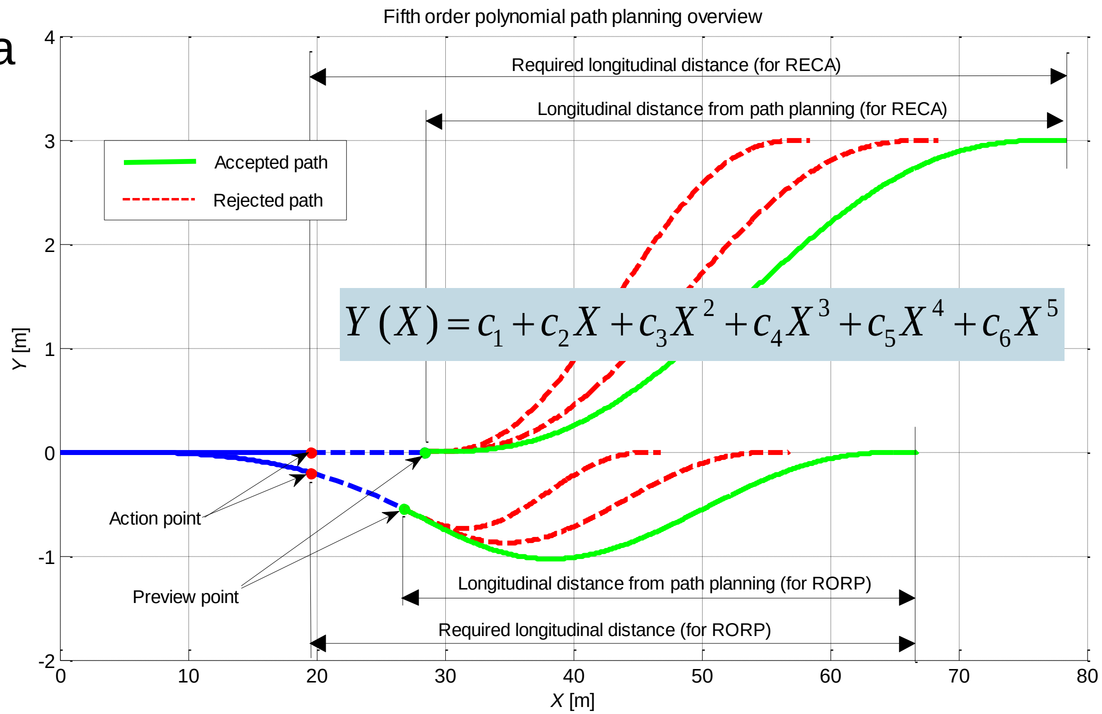
Module 5: Vehicle Path and Stability Control

- Stability control aims to prevent vehicle from being unstable; *e.g.* prevents vehicle from spinning out and rolling over.
- If driver was inattentive, autonomous interventions may help to eliminate other risks on the way like an imminent rear end collision or run off the road.
- Path control is needed for autonomous interventions; when for example:
  - performing a lane change during rear end collision avoidance.
  - returning the vehicle back to the road when running off the road.
- When planning and controlling the path, stability shall also be achieved, then path and stability are needed to be controlled together.

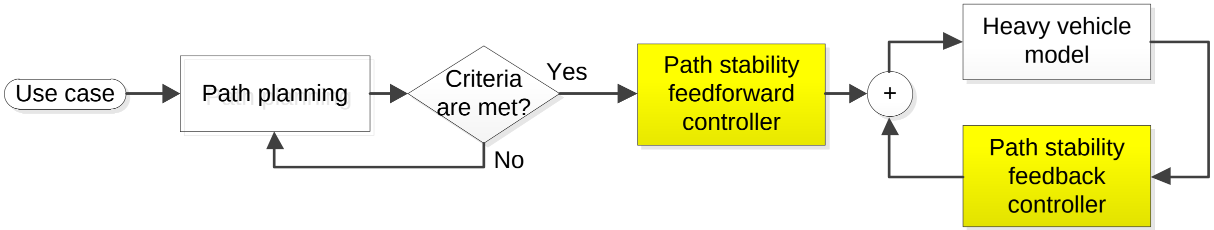
Module 5: Vehicle Path and Stability Control



- Generating a path; *e.g.* a fifth order polynomial.
- Checking stability criteria, *e.g.* maximum lateral acceleration.
- If any of stability criteria was not met, iteratively regenerating a new path until all stability criteria are met.



Module 5: Vehicle Path and Stability Control



- Feed-Forward control; steady state bicycle model is used to calculate steering inputs:

$$\delta_{FF} = \kappa\left(l_e + K_{us}\frac{a_y}{g}\right)$$

where:

$$l_e = l + \frac{\Delta^2}{l}\left(1 + \frac{C_{\alpha r}}{C_{\alpha f}}\right)$$

- Feedback control; linear PD control on yaw angle and its rate.

$$\delta_{FB} = K_p(\psi_{ref} - \psi) + K_d(\dot{\psi}_{ref} - \dot{\psi})$$

where:

$$\psi_{ref} = \tan^{-1}\left(\frac{dY_{ref}}{dX}\right) \qquad \dot{\psi}_{ref} = V\frac{d\psi}{dX} = V\frac{Y''}{1+Y'^2}$$

Module 5: Vehicle Path and Stability Control/ Tutorial

The value for feedforward steering wheel angle is calculated based on (3.38) in Deliverable_5.1_V1.0:

$$\delta = \frac{l_e}{R} + K_{us}\frac{a_y}{g}$$

where δ is wheel angle, l_e is equivalent wheelbase, K_{us} is understeer coefficient. Steering gear ratio (i_{SW}) shall be multiplied to give steering wheel angle. That can also be modified to include curvature (κ) and speed (V) instead of radius and lateral acceleration, as below:

$$\delta_{SWA}^{FF} = \kappa\left(l_e + K_{us}\frac{V^2}{g}\right) i_{SW}$$

where δ_{SWA}^{FF} is feedforward steering wheel angle, $\kappa = \frac{1}{R}$ and $V^2 = \frac{a_y}{\kappa}$.

The values for equivalent wheelbase and understeer coefficient are taken from Chalmers Simulation V1.0.

Intertwined lecture and tutorial overview

Vehicle systems ⇄ Vehicle dynamics theory ⇄ MATLAB/ Simulink simulation model

$$a_x = \dot{v}_x - v_y\dot{\psi}$$

$$\Sigma F = ma$$

$$\dot{z}(t) = f(z,u)$$

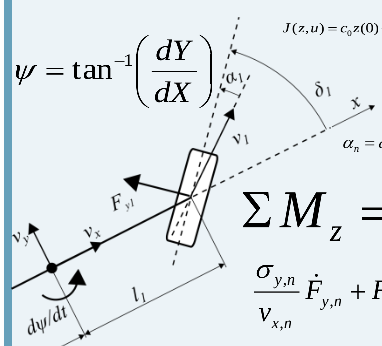
$$\delta = \frac{l}{R} + K_{us}\frac{a_y}{g}$$

$$F = D\sin\{C\arctan[B\alpha - E(B\alpha - \arctan(B\alpha))]\}$$

$$J(z,u) = c_0 z(0) + c_T z(T) + \int_0^T z^T Q z\,dt$$

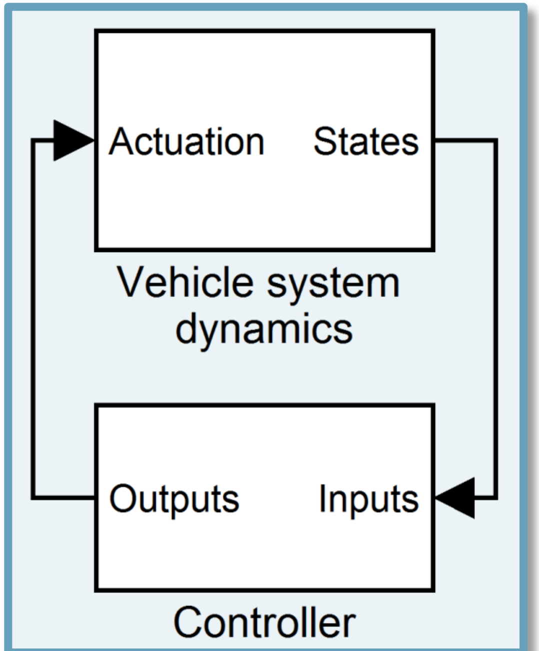
$$\psi = \tan^{-1}\left(\frac{dY}{dX}\right)$$

$$\alpha_n = \delta_n - \arctan\left(\frac{v_{y,n}}{|v_{x,n}|}\right)$$



$$\Sigma M_z = I_{zz}\ddot{\psi}$$

$$\frac{\sigma_{y,n}}{v_{x,n}}\dot{F}_{y,n} + F_{y,n} = F_{y,mf,n}$$



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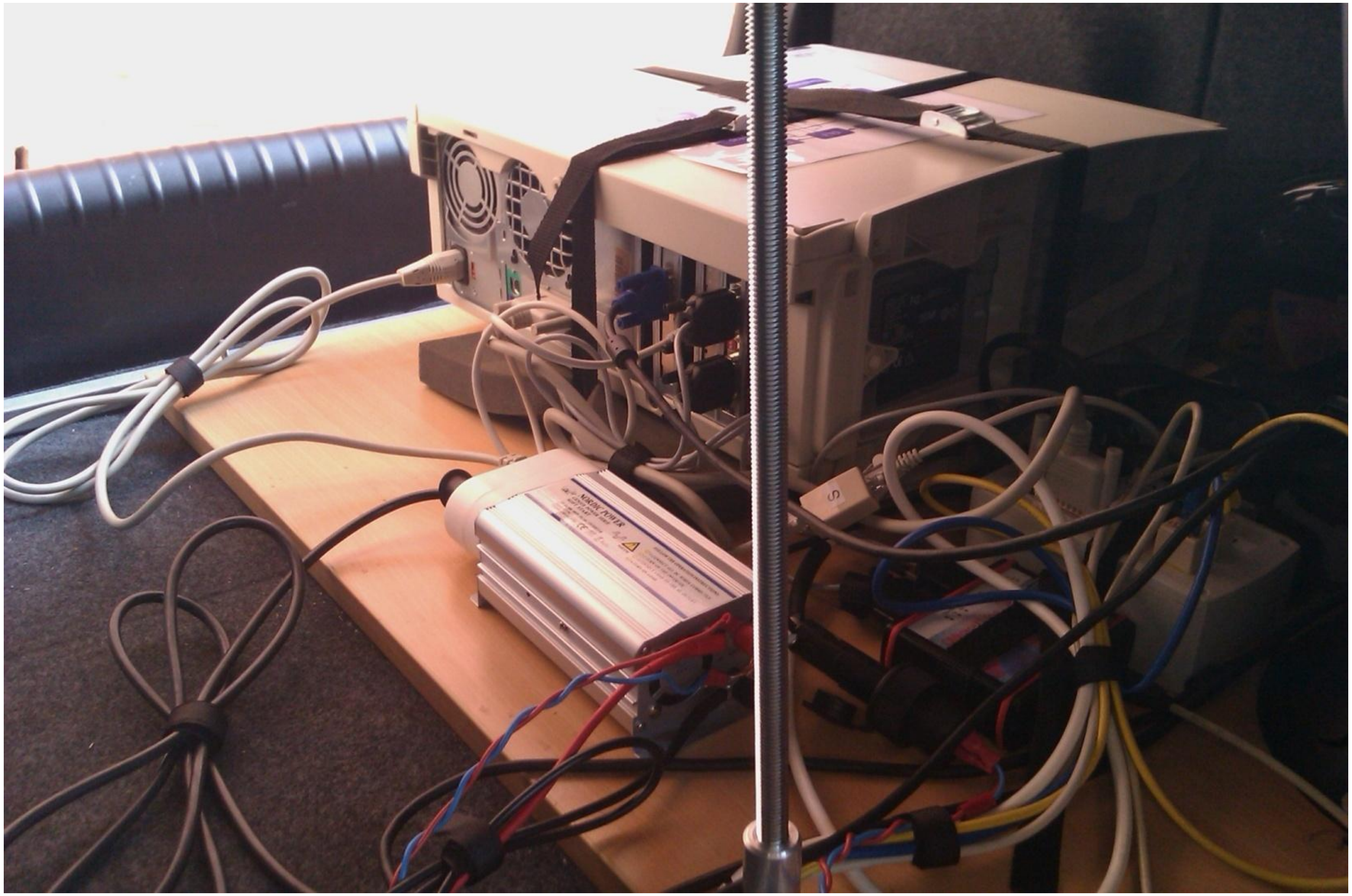
Experimental Vehicle Dynamics

Experimental Vehicle Dynamics

Chalmers Experimental Vehicle (red Saab)

- Dspace/XPC Target Rapid Control Prototyping Hardware and Software
- Extra electro hydraulic brake system

Experimental Vehicle Dynamics



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Accident avoidance by active intervention for Intelligent Vehicles

Thank you.

Co-funded and supported
by the European Commission

SEVENTH FRAMEWORK
PROGRAMME

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